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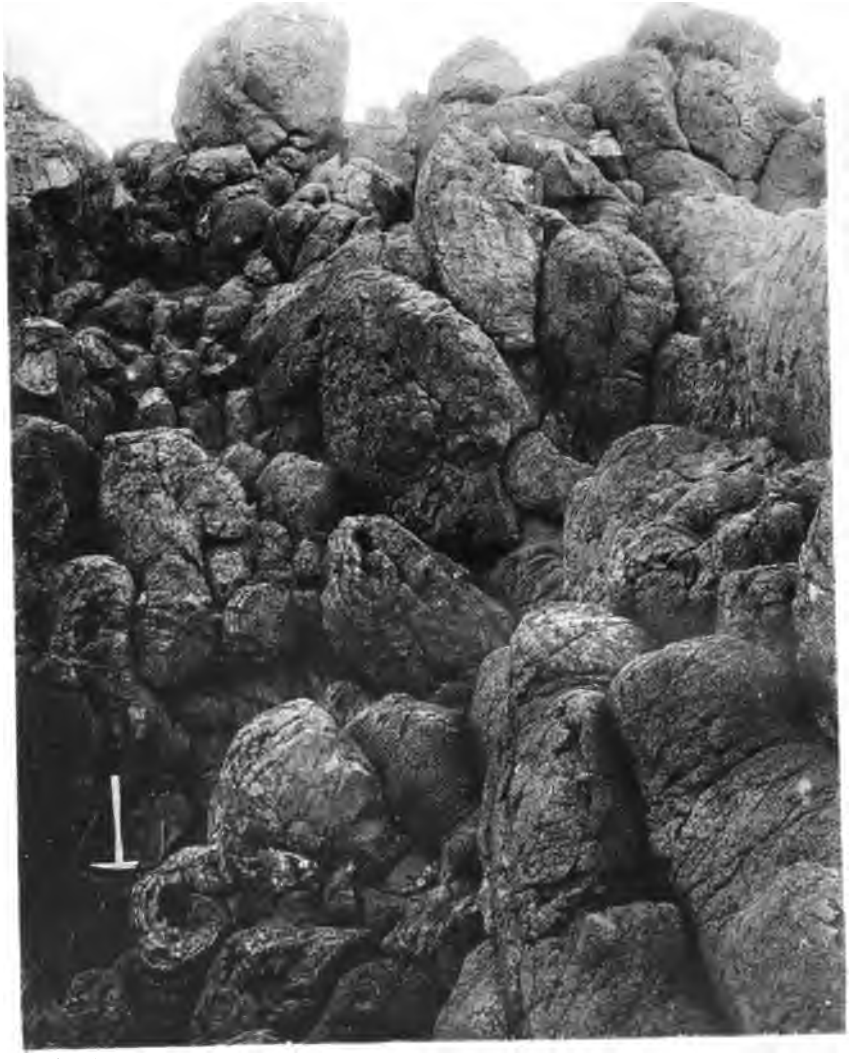

Sack-like or pillow-form structure of Diabase Lava, on shore ¾-mile south of Downan Point, 2½ miles south of Ballantrae.

Gt. Brit.

MEMOIRS OF THE GEOLOGICAL SURVEY

OF THE

UNITED KINGDOM.

THE

SILURIAN ROCKS

OF

BRITAIN.

VOL I.

SCOTLAND.

BY

B. N. PEACH, F.R.S., A.R.S.M., F.G.S.,

AND

JOHN HORNE, F.R.S.E., F.G.S.

WITH

PETROLOGICAL CHAPTERS AND NOTES.

BY

J. J. H. TEALL, M.A., F.R.S., F.G.S.

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PREFACE.

THE present publication, forming the first volume of the Monograph of the Geological Survey on The Silurian Rocks of Great Britain and Ireland, is devoted to the Silurian formations of Scotland. It presents a detailed summary of all that is known up to the present time regarding these early records of the geological history of the country. While the extensive and minute observations of the Geological Survey necessarily fill the greater part of the book, every effort has been made in the historical introduction (Chapter II.) to do full justice to the labours of other observers and to give to each writer his due place in the progress of discovery.

At intervals, during several years, Messrs. Peach and Horne, following up the researches of Professor Lapworth, which supplied a clue to unravel the stratigraphy of this region, have been engaged in a searching investigation of the Silurian Rocks of the South of Scotland. They have traversed, sometimes repeatedly, the various sections of the strata across the length and breadth of the Southern Uplands. They have mapped on the ground the successive rock-zones, traced the variations of these zones from one end of the region to the other, and made voluminous notes regarding their stratigraphy, tectonic structure, palæontology, and petrography. In the course of this work the fossils have been collected mainly by Mr. Macconochie. The large mass of material thus accumulated has been condensed and arranged in the following chapters, which, it is hoped, will form a sufficient guide to future geologists who may desire to study the country described.

The attention of the general reader is specially directed to Chapters III. and IV., which present a condensed account of the various characteristics, stratigraphical, palæontological, and petrographical, of the Silurian Rocks throughout the South of Scotland. Should he desire more detailed information regarding any particular formation he will find it supplied in the subsequent chapters. In these, the country has been divided into a few large tracts, each of which forms a more or less well defined geological area. The rocks of each tract are described in stratigraphical order, beginning with the oldest, and their variations are traced as these are revealed in successive sections across the country. This combination of topographical and stratigraphical treatment seemed to be the most convenient that could be adopted for the purposes of the geological observer.

While both the authors whose names appear first on the title-page have equally collaborated in the collection and working out of the materials for this work, Mr. Peach has been specially entrusted with the drawing of the numerous diagrams introduced into the text, with the preparation of the map and sections, and with the laborious palæontological duties that have been required in dealing with the vast mass of fossils that have been gathered together. To Mr. Horne has fallen the task of arranging the materials and writing nearly the whole of the volume.

Other coadjutors on the staff of the Survey have been Mr. J. J. H. Teall, F.R.S., who has written Chapters IV., XXVI., and XXVII., and has also supplied nearly all the notes on microscopic sections quoted in the text; Dr. Hatch, who while in the service supplied notes on a few microscopic sections of Arenig igneous rocks from the district between Abington and Leadburn; Mr. A. Macconochie, who arranged the lists of fossils inserted in the text, and assisted Mr. Peach in the preparation of the fossil lists given in the Appendix; and Mr. R. Lunn, who took the original photographs from which Plates I. to XVII. have been prepared.

To several fellow-workers outside the Survey cordial acknowledgments for assistance are due. Professor Lapworth, always ready with his valuable aid, named the doubtful species of graptolites referred to him from time to time, revised certain lists of fossils, and has been kind enough to supply the blocks for the Plates of graptolites. Dr. Traquair, F.R.S., furnished the descriptions of the remarkable fossil fishes from the Upper Silurian Rocks of Lanarkshire and Ayrshire. Mr. Malcolm Laurie gave some notes on the Arthropoda from the Gutterford Burn in the Pentland Hills. Mrs. Gray was good enough to prepare for us a list of the fossils collected by her and her family from the Silurian Rocks of the Girvan district, which is inserted in the Appendix, and likewise permitted us to refer to her valuable collection during the examination of that region.

ARCH. GEIKIE.

Geological Survey Office,
28 Jermyn Street, London,
31st May 1899.

CONTENTS.

PAGE

PREFACE, BY THE DIRECTOR-GENERAL - - - - iii

CHAPTER I.

PHYSICAL FEATURES OF THE SILURIAN REGION OF SCOTLAND - 1

CHAPTER II.

HISTORY OF PREVIOUS RESEARCHES AMONG THE SILURIAN ROCKS OF THE SOUTH OF SCOTLAND.

Researches of Hutton, Hall, MacLaren, Carrick Moore - 5-7
" Nicol, Hay Cunningham, Harkness, Salter - 7-10
" Sedgwick, Murchison - - - 10-12
" Harkness, Slimon, Murchison, Carrick Moore 13-14
" Geological Survey prior to 1868 - - 15-16
" Henderson, Brown, Haswell, Davidson - 16-17
" Geological Survey 1868-1887 - - 18-20
" Lapworth - - - 20-25, 29-33, 36
" Geological Survey 1888-96 (Dr. Hinde) - 33-6

CHAPTER III.

GENERAL DESCRIPTION OF THE SILURIAN ROCKS OF THE SOUTHERN UPLANDS.

I. STRATIGRAPHY:—

Geographical Sub-divisions of the Tableland (Southern, Central, and Northern Belts, Girvan Area) - - 37
Arenig—Rocks, Fossils, Conditions of Deposition - - 38-41
Llandeilo— " " " " - - 41-7
Caradoc— " " " " - - 47-56
Llandovery and Tarannon " " " " - - 56-63
Wenlock and Ludlow " " " " - - 63-7
Downtonian " " " " - - 67-9

II. TECTONIC ARRANGEMENT OF THE STRATA:—

Period of Elevation of Tableland; Isolation of Sub-formations by Denudation - - - - 69
Types of Curvature - - - - - 70
Structural Features of the Silurian Belts - - - 71-4
Modification of Outcrop by Pitch of Folds; Schistosity and Cleavage - - - - - - 75

TECTONIC ARRANGEMENT OF THE STRATA (*continued*)— PAGE

Intrusive Igneous Rocks earlier than the Upper Old Red Sandstone - - - - - - 76
Contact Metamorphism; Excavation of the Valley System - 77-8
Table showing relative thicknesses of Silurian strata in South of Scotland - - - - - 79
Table showing sub-divisions and thicknesses of Upper Silurian strata - - - - - - 80-81
Table showing sub-divisions and thicknesses of Lower Silurian strata - - - - - - 82-3

CHAPTER IV.

By J. J. H. Teall, F.R.S.

PETROGRAPHY OF THE IGNEOUS ROCKS IN THE LOWER SILURIAN FORMATIONS IN THE SOUTHERN UPLANDS.

Lavas (diabase and "diabase-porphyrite") and tuffs - 84-8
Soda-felsite lava, Peeblesshire - - - - 88
Perlitic felsite lava ,, - - - - 89
Serpentine, Gabbro, Dolerite, &c. - - - - 89-91

CHAPTER V.

DETAILED DESCRIPTION OF THE SILURIAN REGION OF THE SOUTHERN UPLANDS.

I. THE CENTRAL BELT.

The Moffat Black Shale Series (typical sections):—
Dobb's Linn, Moffatdale - - - - 92-100
Craigmichan Scaurs, Moffatdale - - - - 100-7

CHAPTER VI.

THE CENTRAL BELT—THE MOFFAT SERIES (*continued*).

BLACK SHALE BANDS SOUTH OF MOFFATDALE:—
i. Band of Bodesbeck Summit, Range Cleuch, Muckra, and Crosscleuch to St. Mary's Loch - - - 108
ii. Band of Thirlstane Score - - - - 110
iii. Band from Pot Law by Peniestone Knowe to Moory Sike 110
iv. Band from Brockhope Burn by Whitehope and Berry-knowe to Eldinhope, Vale of Yarrow - - 112
v. Mountbenger Band - - - - - 113
vi. Band from Bellcraig by Craigmichan Scaurs, Entertrona, the Upper Ettrick, to Berrybush - - - 114
vii. Shorthope and Phawhope, Upper Ettrick - - 119
viii. Ettrickbridge-end section - - - - 121

CHAPTER VII.

THE CENTRAL BELT—THE MOFFAT SERIES (*continued*).

BLACK SHALE BANDS NORTH OF MOFFATDALE:—
Frenchland Burn, Garpol Water, &c. - - - 130-1
Hartfell section - - - - - - 133
Ruttonside, Headshaw Linn, &c. - - - - 138

BLACK SHALE BANDS NORTH OF MOFFATDALE (*continued*)— PAGE.

Mid Craig, Loch Skene, &c. - - - - 139
Glengaber Burn, Douglas Burn, &c. - - - 140-1
Fruid Water, Tweed Valley - - - - 142-3
Summary of the evidence regarding modification of the Moffat Zones between Dobb's Linn and northern margin of Tarannon Area (Sheet 16 of Map) - - - 144

CHAPTER VIII.

THE CENTRAL BELT—THE MOFFAT SERIES (*continued*).

BLACK SHALE BANDS IN THE AREA BETWEEN THE ANNAN AND THE NITH :—

The Glenkiln section - - - - - 146
Duffkinnel Water, &c. - - - - - 150
District of Wee Queensberry Hill - - - 152
Crook Burn, Daer Water - - - - 155

BLACK SHALE BANDS IN THE AREA BETWEEN NITHSDALE AND THE RIVER CREE :—

Bogrie and Castramon, &c. - - - - 156
Water of Urr - - - - - - 159
Barend and Auchenvey, &c. - - - - 161
Glen Burn and Skeoch - - - - 163
Trowdale, Crossmichael, and Lawrieston, &c. - - 164
River Cree, one mile north of Newton-Stewart - - 172

CHAPTER IX.

THE CENTRAL BELT—THE MOFFAT SERIES (*continued*).

BLACK SHALE BANDS BETWEEN THE CREE AND THE MULL OF GALLOWAY :—

Glenling, Crailloch, and Ballaird Black Shale Bands - 174
Culroy Band - - - - - - - 180
Clanyard Bay, Drumbreddan Bay, &c. - - - 183
Summary of the evidence regarding the Moffat Series, on the shore between the Mull of Galloway and Money Head (Sheets 1 and 3 of Map) - - - 189

CHAPTER X.

THE CENTRAL BELT—THE MOFFAT SERIES (*continued*).

BLACK SHALE BANDS EAST OF PEEBLES AND SELKIRK :—

Rhymer's Glen, Melrose, Coldshiels Loch, &c. - - 190
Leithen Water, Lugate Water, Garnscleuch Burn, &c. - 193-7

CHAPTER XI.

THE CENTRAL BELT (*continued*).

TARANNON ROCKS :—

Northern Base-line of Llandovery Rocks of the Central Belt 198
North-Eastern District - - - - - 201-9
Moffat District - - - - - - 210
District between the Nith and the Cree - - - 213
District west of the Cree - - - - - 215

CHAPTER XII.

II. The Northern Belt. Page.

Arenig, Llandeilo, and Caradoc Formations in the District between Abington and Eddleston:—

Basin of the Wandel Water - - - 217-25
Abington District east of the Clyde - - 225-32
Culter Water District - - - - 232-41
Biggar Water District - - - - - 241
District stretching from the basins of the Tarth and Lyne Waters to the Midlothian Coal-field - - - 247
Eddleston and Drochil Castle District, &c. - - 251

CHAPTER XIII.

The Northern Belt (*continued*).

Arenig, Llandeilo, and Caradoc Formations in the District between Wrae, Peeblesshire, and the Lammermuir Hills:—

Volcanic and Sedimentary Rocks of Wrae, Glencotho, Drummelzier, Hamilton Hill, and Winkston - 255-62
Stobo Slate Quarries, &c. - - - - 262
Head Waters of the Leithen, &c. - - - 264
Basin of the Heriot Water - - - - 267
Gala Water, Leader Water Basin - - - 270-1
Kelphope Burn, Friar's Nose - - - - 273-5
Lammermuir Hills - - - - - 275-9

CHAPTER XIV.

The Northern Belt (*continued*).

Arenig, Llandeilo, and Caradoc Rocks in the Leadhills District:—

Glengonner Water and its tributaries, including Bellgill Burn, Kirk Burn, Raven Gill, Glencaple Burn, &c. - 280-9
Wanlock Water and tributaries, including Glengaber Burn, Back Burn, Duntercleuch Burn, Glenmarch-Hope Burn, and Sowen Burn - - - - 290-3
Snar Water near Wanlockhead, and tributaries - 293-4
Cog Burn and its tributaries (west from Wanlockhead) 295
Conrig Burn, Fingland Burn, Conrig Hill, Glendyne Burn - - - - - 298-302

CHAPTER XV.

The Northern Belt (*continued*).

Arenig, Llandeilo, and Caradoc Formations of the Leadhills District (*continued*):—

Bail Hill Volcanic Area - - - - - 303-9
Basin of the Crawick Water, including Kiln, Polcraig, Spotfore, Back, and Polthistly Burns, Eller Scaur, Wanlock Water (lower section), Glenrae Burn, Nether Whitecleuch Burn - - - - 309-21

THE NORTHERN BELT (*continued*)— PAGE.

Basin of the Duneaton Water (southern portion), including Snar Water (lower section), Glentewing Burn, Glenliscleuch Burn - - - - - - 321-3
Fossiliferous Conglomerate of Duntercleuch and Glendowran, Leadhills - - - - - 323-4
Representatives of Glenkiln Shales and asssociated sediments, from the Sanquhar Coal-field to the Clyde near Wandel Mill - - - - - - 325-9
Black Shale Bands in the basins of the Elvan and Menock Waters, and in the Tributaries of the Nith near Kirkbride - - - - - - - 328

CHAPTER XVI.

THE NORTHERN BELT (*continued*).

ARENIG, LLANDEILO, AND CARADOC FORMATIONS BETWEEN NITHSDALE AND LOCH DOON:—

i. Black Shale Bands between Burnmouth, Nithsdale, and Dalshangan north of Dalry - - 333-45
ii. Black Shale Bands between Upper Appin, Shinnel Water, and Arndarroch, River Ken - - 345-6
iii. Black Shale Bands from Corfardine, Scar Water, by Clodderoch and Margree to Gordonston near Dalry - - - - - 347-51
iv. Black Shale Bands between Whing Burn, Euchan Water, and Benniner Hill, near Cairnsmore of Carsphairn - - - - - 351-64
Band of Volcanic Rocks between the Kello and Euchan Waters (Caradoc) - - - - - 364

CHAPTER XVII.

THE NORTHERN BELT (*continued*).

ARENIG, LLANDEILO, AND CARADOC FORMATIONS BETWEEN NITHSDALE AND LOCH DOON (*continued*):—

Volcanic Area two miles E.S.E. of New Cumnock - 366
Glenkiln-Hartfell Shales in Polmorlach and Polhote Burns - - - - - - 368
Dalmellington District - - - - - 371-5
Carsphairn District - - - - 376-82
Sediments mainly of Caradoc age overlying the Glenkiln-Hartfell Black Shales between the Nith and Loch Doon Granite mass - - - - - - 382-6

CHAPTER XVIII.

THE NORTHERN BELT (*continued*).

ARENIG, LLANDEILO, AND CARADOC FORMATIONS BETWEEN THE MERRICK HILLS AND THE PORTPATRICK COAST-LINE:—

i. Black Shale Bands between Lamachan, Loch Dee, and Dunragit near Glenluce - - 387-95

THE NORTHERN BELT (*continued*)— PAGE.

ii. Black Shale Bands between Glen Trool and New Luce - - - - - 395-401
Black Shale Bands of Morroch Bay, Colfin, and Garthland, in Portpatrick District - - - 401-8
Shore Section from Corsewall Lighthouse to Portpatrick - - - - - - 410-5
Cairn Ryan District - - - - - 416
Craiglure Lodge, north-west of Loch Doon - - 419
Sediments of Caradoc age overlying the Glenkiln-Hartfell Shales to the north of the Llandovery Area in Wigtownshire, and the western part of Kirkcudbrightshire - - - - - - 419

CHAPTER XIX.

III. THE GIRVAN DISTRICT.

ARENIG-LLANDEILO VOLCANIC SERIES OF BALLANTRAE AND ASSOCIATED SEDIMENTS:—

Area between Glen App and Ballantrae—
Portandea section - - - - - 421
Glen Currarie, Shallochbraik Burn, and Brakness Hole 424
Shore section between Currarie and Downan Point - 426
Area between the valley of the Stinchar and Byne Hill—
Bennane Head, shore section - - - - 432
Coast section from Bennane Head to Balcreuchan Port 438
Summary of the evidence regarding the typical Bennane Head section - - - - - 441
Pinbain Shore section - - - - 442
Pinbain to Kennedy's Pass, shore section - - 444
Mains Hill, Ballantrae, and Balnowlart - - 446
Knockdolian Hill, Ballantrae - - - - 449
Inland Volcanic Area south of Stinchar - - 451
Central Volcanic Area between Bennane Head and Lochton - - - - - - 454
Northern Inland Volcanic Area, including Pinbain Hill 459
Small Inliers of Arenig Volcanic Rocks near the main Volcanic Area of Ballantrae - - - 460

CHAPTER XX.

THE GIRVAN DISTRICT (*continued*).

INTRUSIVE IGNEOUS ROCKS:—

Serpentine, Gabbro, Dolerite, Epidiorite, Granite - 465-83

CHAPTER XXI.

THE GIRVAN DISTRICT (*continued*).

LLANDEILO-CARADOC SEDIMENTARY (GIRVAN) SERIES:—

THE BARR SERIES (UPPER LLANDEILO)—

Sub-divisions of the Barr Series - - - - 484
Sections in the valley of the Stinchar near Barr, Benan Burn, Minuntion Quarry, Dularg - - - 485
Sections in the Assel Valley - - - - 491

THE GIRVAN DISTRICT (*continued*)— PAGE.

Sections round the margin of Arenig Volcanic Plateau, showing unconformability at base of Girvan Series—Aldons, Millenderdale, Byne Hill, and Kennedy's Pass - 494-8
Inliers of the Barr Series in the Volcanic Plateau—Craigneil Castle, Bougang, Knockdolian Barns - 498-500
Additional exposures south of the Girvan Valley—Dinvin Hill, Pinmacher, Glendrissock Hill, Trowier Hill, Dow Hill - - - - - - - 500-1
Sections north of the Girvan Valley—Craighead Quarries, Thunderton, and Glenlochrie.
Geological Horizon of the Barr Series—Summary of the evidence regarding the local elevation of the Arenig Volcanic Rocks, &c. - - - - - 506

CARADOC FORMATION.—

Generalised Section of the Caradoc strata - - - 508
i. Balclatchie Group :—
Sections—Balclatchie Bridge, Barbae, Daldowie, Millenderdale, Laggan Gill, Ardmillan Braes - 508-14
ii. Ardwell Group, iii. Whitehouse Group, iv. Barren Flagstone Group, exposed on Ardmillan Shore and in Penwhapple Glen - - - - 515-22
Caradoc Strata of the Craighead Inlier—
iv. Barren Flagstone Group, v. Drummuck Group - - 522-6

CHAPTER XXII.

THE GIRVAN DISTRICT (*continued*).—UPPER SILURIAN :—

i. *LLANDOVERY.*

Sub-divisions of the Llandovery Rocks - - - 527
1 Craighead Inlier - - - - - 528
2. District of Penwhapple Glen, Saugh Hill, and Camregan 533
3. Sections east of Penwhapple Glen - - - 537
4. Sections west of Penwhapple Glen - - - 539
5. Shalloch and Woodland, south of Girvan - - 540

ii. *TARANNON.*

Sub-divisions of Tarannon Series - - - - 544
(*a*) Penkill Group, (*b*) Bargany Group, (*c*) Drumyork Flagstones - - - - - - 545-7

iii. *WENLOCK.*

Blair, Knockgardner, and Straiton Beds - - 547-50

CHAPTER XXIII.

IV. THE SOUTHERN BELT.

WENLOCK AND LUDLOW :—

1. Burrow Head, Wigtownshire - - - - 551
2. District between the Dee and the Nith - - - 552
3. District between Dumfries and Langholm - - 557
4. District between Langholm and the River Jed - - 558
5. Inlier of Riccarton and Wolfelee - - - 560
6. Inliers on the northern slopes of the Cheviot Hills - 561

CHAPTER XXIV.

PAGE.

V. UPPER SILURIAN ROCKS NORTH OF THE TABLELAND.

LANARKSHIRE AND AYRSHIRE:—

Recent discoveries of organic remains in Silurian Rocks - 564
Note by Dr. Traquair on the Fish Fauna - - - 565
Reasons why the Downtonian Rocks are now classed with the Silurian System - - - - - 567
Classification of the Upper Silurian Rocks in Lanarkshire - 569
1. The Lesmahagow Inlier - - - - 570
2. The Anticline of the Hagshaw Hills - - - 581
3. The Carmichael Burn Inlier. - - - - 586
4. The small exposure south of Tinto. - - - 588

CHAPTER XXV.

UPPER SILURIAN ROCKS NORTH OF THE TABLELAND (*continued*).

THE PENTLAND HILLS - - - - - 589
i. Inlier extending from the Lyne Water by the North Esk to Green Law - - - - - 590
Sections in the North Esk and Lyne Water - 590-602
Note by Mr. Malcolm Laurie on the *Arthropoda* of the Gutterford Burn - - - - - 594
Summary of the evidence regarding this Silurian Inlier - 603
ii. Habbie's Howe Inlier - - - - - 604
iii. Bavelaw Castle Inlier - - - - - 604
iv. Craigenterrie Inlier - - - - - 605

CHAPTER XXVI.

By J. J. H. Teall, F.R.S.

GRANITE MASSES:—

1. Criffel and Dalbeattie Mass - - - - 607
2. Loch Dee Mass - - - - - - 610
3. Cairnsmore of Fleet Mass - - - - 617
Summary of the principal results obtained from the petrographical study of the Galloway Granites - - 621

DYKES:—

1. Porphyrites, 2. Diorites, 3. Mica-traps - - 625-31

CHAPTER XXVII.

By J. J. H. Teall, F.R.S.

CONTACT METAMORPHISM ROUND THE GALLOWAY GRANITES:—

Minerals present in the altered rocks - - - 634-9
Altered sedimentary rocks - - - - 639-47
Altered igneous rocks - - - - 647-51

CHAPTER XXVIII.

Economic products of the Silurian Rocks of the South of Scotland - - - - - - 653

APPENDIX.

PAGE

I. Lists of Fossils from the Silurian Rocks of the South of Scotland:— 659

1. General List of the Graptolites from the Silurian Rocks of the South of Scotland, - - - - 661

2. General List of Fossils, exclusive of Graptolites, from the Silurian Rocks of the South of Scotland, in the Collections of the Geological Survey, - - 667

3. List of Fossils, prepared by Mrs. Gray, from the Collection made by her from the Silurian Rocks of the Girvan District of the South of Scotland, - 686

4. Complete List of Fossils from the Stinchar Limestone Series (Upper Llandeilo) of the Girvan District of the South of Scotland, - - - - 698

5. Comparative Table of Fossils from the Caradoc Rocks of Balclatchie, Leadhills, Wallace's Cast, Kilbucho, Glencotho, Wrae, and Winkston, - - - 700

6. Comparative Table of Fossils from the Wenlock-Ludlow Rocks of the South of Scotland, - - 708

II. List of Works referring to the Geology of the Silurian Rocks of the South of Scotland, - - - 717

Index.

Plates at end of volume (see under List of Illustrations), 733

LIST OF ILLUSTRATIONS.

			Page
Fig.	1.	Normal Folds	70
„	2.	Isoclinal Folds	70
„	3	Composite Folds	72
„	4.	Section of Birkhill Black Shales exposed in Garpol Burn, near Moffat, showing reduplication of strata by folding and faulting	72
„	5.	Ground-plan, Dobb's Linn, Moffatdale (after Lapworth)	93
„	6.	Section in Dobb's Linn	94
„	7.	Section in lateral gorge, Dobb's Linn	95
„	8.	Section of strata in Dobb's Linn	96
„	9.	Section in Dobb's Linn	98
„	10.	Section in Craigmichan Scaurs, Moffatdale	101
„	11.	Plan of strata in Rae Grain, Selcoth Burn	102
„	12.	Section in Rae Grain, Selcoth Burn	104
„	13.	Plan and sections in Selcoth Burn	106
„	14.	Section in Trow Grain, Ettrick Water	109
„	15.	Section in Moory Sike, above Loch of the Lowes	111
„	16.	Section in Hodge Burn, Bellcraig, Moffat	114
„	17.	Generalised section from Black Knowe across Ettrick Water to Phawhope Kips	117
„	18.	Generalised section from Potburn to Ettrick Pen	117
„	19.	Plan of strata in the River Ettrick above Ettrickbridge-end	121
„	20.	Section in River Ettrick from Manse Cliff to foot of Baillie Burn	123
„	21.	Section in River Ettrick at bend above Manse, Ettrickbridge-end	124
„	22.	Section across River Ettrick, southwards from Kirkhope Farm	126
„	23.	Section in River Ettrick from bend above Kirkhope Farm through the Gait Crook	127
„	24.	Generalised section across the "Score" at Hartfell Spa	135
„	25.	Plan of strata in Glenkiln Burn, Kirkmichael, Dumfriesshire	146
„	26.	Section in Glenkiln Burn, near foot of Lambfoot Linn	147
„	27.	Section in Glenkiln Burn	148
„	28.	Plan of strata in Pishnack Burn, Water of Ae, Dumfriesshire	152
„	29.	Section near foot of Pishnack Burn	153
„	30.	Section in Bogrie Burn, Glenessland, Dumfriesshire	156
„	31.	Section across Glen Burn, north-east of Kirkcudbrightshire	164
„	32.	Section across Trowdale Glen, Water of Urr, Kirkcudbrightshire	165

			Page.
Fig.	33.	Section across Tottlehams Burn, Water of Urr -	167
„	34.	Generalised section from Garheugh to Alticry, Wigtownshire - - - - -	175
„	35.	Generalised section across the Black Loch and Kirwan to Drumblair, Wigtownshire - -	176
„	36.	Generalised section from Crailloch to Glenling, Wigtownshire - - - - -	177
„	37.	Plan of Gillespie Burn, Culroy, Wigtownshire -	180
„	38.	Section across Gillespie Burn - - -	181
„	39.	Section across Gillespie Burn - - -	182
„	40.	Section in Clanyard Bay, near Mull of Galloway -	185
„	41.	Plan of shore at Dove Cave, west coast of Galloway -	188
„	42.	Plan of strata, head of Hawkwood Burn, Wandel Water, Lanarkshire - - - -	218
„	43.	Section at the head of Hawkwood Burn, Wandel Water - - - - - -	219
„	44.	Section from Rough Gill to Deil's Barn Door, Wandel Water - - - - - -	220
„	45.	Section in Lead Burn, Wandel Water - -	221
„	46.	Generalised section from Wallace's Cast to Rome Hill, Wandel Water - - - -	226
„	47.	Section from Arbory Hill to Camps Water, Clydesdale	227
„	48.	Section, Southwood Burn, Abington, Clydesdale -	228
„	49.	Section, Castle Hill, Abington - - -	229
„	50.	Section, railway cutting opposite Kirkton, Abington -	230
„	51.	Generalised section, Cowgill Rig to Duncan Gill, Culter Water - - - - -	234
„	52.	Section in Key Gill, Culter Water, Lanarkshire -	236
„	53.	Section in Howe Gill, Culter Water - - -	237
„	54.	Section in Gair Gill, Culter Water - - -	239
„	55.	Section from Snaip to Culter, Culter Water - -	240
„	56.	Section from Blindewing to Goseland Hill, Kilbucho Burn, Peeblesshire - - - -	241
„	57.	Generalised section from Manse Rig, Kilbucho ,to Hartree, Peeblesshire - - - -	242
„	58.	Section, Pisgah Hill, Biggar Water, Peeblesshire -	244
„	59.	Generalised section from Broughton to Broughton Knowe, Peeblesshire - - - -	245
„	60.	Generalised section across the Broughton Heights, from Harestanes, near Castle Craig, to Cowie Muir Hass, Peeblesshire - - - -	245
„	61.	Section near Riddenlees, Peeblesshire - -	248
„	62.	Plan of quarries at Wrae, Peeblesshire - -	256
„	63.	Plan of strata, Hope Burn, Heriot Water - -	268
„	64.	Section at head of Gully, Hope Burn, Heriot Water -	268
„	65.	Section in a tributary of Kelphope Burn, head of Lauderdale - - - - -	273
„	66.	Section in Kelphope Burn, head of Lauderdale -	274
„	67.	Section, Papana Water, two miles south of Garvald -	277
„	68.	Section exposed in the Clowgill Burn, Glengonner Water, Lanarkshire - - - -	282
„	69.	Section in the Kirk Burn, Glengonner Water -	284
„	70.	Section along dividing ridge between Kirkgill and Glencaple Burn, Glengonner Water - -	284

			Page.
Fig.	71.	Plan of strata, head of Raven Gill, Glencaple, Lanarkshire	287
„	72.	Section across the head of Raven Gill	287
„	73.	Section across the Bail Hill Volcanic Area, Dumfriesshire	304
„	74.	Section across Bail Hill Volcanic Area	304
„	75.	Section across Bail Hill Volcanic Area, from Guffock Hill to Sanquhar Coal-field	307
„	76.	Plan of the strata in Spotfore Burn	314
„	77.	Section in Spotfore Burn	315
„	78.	Plan of strata in a tributary of Burnsands Burn, Nithsdale	335
„	79.	Section, tributary of Burnsands Burn	335
„	80.	Section in Chanlock Water, Chanlockhead	337
„	81.	Plan and section of strata, Dibbin Lane, Dalwhat Water	340
„	82.	Plan of strata in Pulharrow Burn	345
„	83.	Plan of strata in Whing Burn, south-west of Sanquhar	352
„	84.	Section in Whing Burn	353
„	85.	Plan of strata near head of Glenlarie Burn, Sanquhar	355
„	86.	Section „ „ „ „	356
„	87.	Plan of strata in streamlet near Polgown, Scar Water	357
„	88.	Section along the streamlet shown in Fig. 87	358
„	89.	Ground-plan of strata in Lorg Burn and Rough Craig, Water of Ken, Kirkcudbrightshire	359
„	90.	Section along the Rough Craig, as in Fig. 89	360
„	91.	Section in Lorg Burn, Water of Ken	361
„	92.	Plan of strata in Crag, Cairnsgarroch, Carsphairn	380
„	93.	Section of Crag, Cairnsgarroch, Carsphairn	381
„	94.	Plan of strata in Lagbaes Burn, Cardorkin, Kirkcudbrightshire	388
„	95.	Section across Lagbaes Burn, Cardorkin	389
„	96.	Plan of strata near Taunylaggie House, Wigtownshire	398
„	97.	Plan of strata in Morroch Bay, Wigtownshire	402
„	98.	Section across the strata in Morroch Bay	403
„	99.	Section of strata at Portandea, south of River Stinchar	422
„	100.	Section at Knockgown, north of Currarie, Ballantrae	427
„	101.	Section in Wilson's Burn, between Currarie and Downan	430
„	102.	Plan of strata on the shore, Bennane Head, Ballantrae	433
„	103.	Section on the shore, Bennane Head, Ballantrae	434
„	104.	Plan of strata on shore, Pinbain	442
„	105.	Section of strata on shore, Pinbain	443
„	106.	Generalised section from Ballantrae to Glen App, Ayrshire	447
„	107.	Section across Knockdolian from Bougang to Knockdhu, Ayrshire	449
„	108.	Generalised section from Water of Assel, across Daldowie Hill to Pinmore Mains, South Ayrshire,	461
„	109.	Section across Craighead Inlier	462
„	110.	Generalised section across the Ballantrae Volcanic Area, from Bennane Head to Beneraird	467

PAGE.

Fig. 111. Generalised section across Benan Hill from Tramitchell Limestone Quarry to River Stinchar - - 486
„ 112. Generalised section across Byne Hill from Craig Skelly to Millenderdale - - - - 497
„ 113. Section of the strata on Ardmillan Shore, Ayrshire (after Lapworth) - - - - - 516
„ 114. Section of strata exposed in Penwhapple Glen, Ayrshire (after Lapworth) - - - 520
„ 115. Section across Quarrel Hill and Rough Neuk from Thunderton Hall to Glenshalloch - - - 531
„ 116. Generalised section across the Girvan Area from Drummuck to River Stinchar - - - 548
„ 117. Section across the Lesmahagow Upper Silurian Inlier from Seggholm to Yondertown - - - 571
„ 118. Section across the Hagshaw Upper Silurian Inlier, through Parishholm, Douglas Water, Lanarkshire 584
„ 119. Generalised section across the Upper Silurian Inliers of Lesmahagow and the Hagshaw Hills - - 587
„ 120. Section across the Upper Silurian Rocks of the Pentland Hills, exposed in the North Esk and its tributaries - - - - - - 592
„ 121. Section across the Upper Silurian Rocks of the Pentland Hills, exposed in the Lyne Water - 601

PLATES.

PLATE I. Sack-like or pillow-form structure of diabase-lava, on shore ¾-mile south of Downan Point, 2½ miles south of Ballantrae - - - Frontispiece
„ II. Limestone filling spaces between pillow-form masses of lava, exposed on beach near Downan, 1½ miles south of Ballantrae - - to face page 40
„ III. Isoclinal folds in green greywacke, mudstones, and shales, Currarie Point, 3 miles south of Ballantrae - - - - - to face page 72
„ IV. Limestone filling spaces between pillow-form masses of lava on shore near Downan, 1½ miles south of Ballantrae - - - to face page 428
„ V. Vesicular structure in pillow-mass of lava, on beach near Downan, 1 mile south of Ballantrae to face page 430
„ VI. Radiolarian chert filling spaces between pillow-form masses of lava, on shore at Portandea, 5 miles south-west of Ballantrae - - to face page 431
„ VII. Folds in radiolarian chert, stack on shore at Bennane Cave, 2 miles north of Ballantrae - to face page 434
„ VIII. Alternation of tuff and radiolarian chert at Bennane Cave, 2 miles north of Ballantrae - to face page 436
„ IX. Folded radiolarian chert and tuff, cliff south of Bennane Cave, 2 miles north of Ballantrae - to face page 437
„ X. Volcanic agglomerate in vertical beds, Bennane Head, 2½ miles north of Ballantrae - to face page 438
„ XI. Ashy mudstone and chert, with graptolites adhering to pillow-form surface of lava, shore near Balcreuchan Port, 3⅓ miles north of Ballantrae - to face page 439

PAGE.

Plate XII. Volcanic agglomerate, Stockenray Bay, 1¼ miles north of Lendalfoot - - - to face page 445
„ XIII. Porphyritic lava, "diabase-porphyrite," Stockenray Bay, 1½ miles north of Lendalfoot - to face page 446
„ XIV. Junction of dolerite dyke with serpentine, stack on shore, 300 yards north of Lendalfoot to face page 480
„ XV. Benan conglomerate, shore at Kennedy's Pass, 4 miles south of Girvan - - - to face page 498
„ XVI. Benan conglomerate, shore 4 miles south of Girvan to face page 500
„ XVII. Folded flagstones and shales (Ardmillan series), shore, 3¾ miles south of Girvan - - to face page 515

PLATES (at End of Volume).

„ XVIII. Fig. 1. Basic Lava, 350 yards north of Port Vad, Ballantrae, Ayrshire.
„ 2. „ „ „ „
„ XIX. „ 1. Lapilli in Basic Lava, on shore, north of Port Vad,
„ 2. Porphyritic Lava, on shore, 400 yards south of fifth milestone from Girvan.
„ XX. „ 1. Plagioclase-hornblende-rock, Littleton Hill, Colmonell.
„ 2. Plagioclase-hornblende-rock, west of Balhamie Hill, Ayrshire.
„ XXI. „ 1. Soda-felsite, crest of Hamilton Hill, Peeblesshire.
„ 2. Perlitic-felsite, Winkston Hill, two miles north of Peebles.
„ XXII. „ 1. Granulitic Gabbro, Craighill, Colmonell, Ayrshire.
„ 2. Dolerite from centre of dyke, Lendalfoot, Ayrshire.
„ XXIII. „ 1. Hornblende-picrite, west of Balhamie Burn, Ayrshire.
„ 2. Ophitic Dolerite, Byne Hill, Ayrshire.
„ XXIV. „ 1. Ophitic Dolerite, Byne Hill, Ayrshire.
„ 2. Gneissose Granitite, Southwick, Kirkcudbrightshire.
„ XXV. „ 1. Quartz-biotite-hyperite, Black Laggan, Loch Dee.
„ 2. Camptonite, Black Gairy Hill, near Loch Dee.
„ XXVI. A. Arenig and Lower Llandeilo Graptolites.
B. Upper Llandeilo (Glenkiln) Graptolites.
„ XXVII. C. Caradoc (Hartfell) Graptolites.
D. Upper Silurian Graptolites.

MAP.

Index Map of the Silurian Rocks of the South of Scotland, with coloured sections, viz.:—

No. 1. Section from Pentland Hills to Riccarton.
No. 2. Section from Lesmahagow to the Solway, near Kirkcudbright.
No. 3. Section from Craighead, near Girvan, to Burrow Head.

THE SILURIAN ROCKS OF SCOTLAND.

CHAPTER I.

Physical Features of the Silurian Region of Scotland.

THE Southern Uplands form the southmost of the three transverse belts into which Scotland is divided in accordance with its topographical features and geological structure. Bounded on the south by the Solway Firth and the Cheviot Hills and on the north by the central lowlands, they stretch as a continuous band of high ground from the North Sea to the Irish Channel.

In the central and eastern districts, the scenery of these pastoral uplands is wonderfully uniform. It may be described as a succession of smooth undulating hills and bleak moorland, which are traversed by a series of deep and narrow valleys, and covered with grass, heath, or occasionally with peat. Indeed it is mainly in the glens draining the highest parts of the plateau that smooth slopes give place to precipitous crags. In the south-western districts, owing to the presence of large masses of granite, the scenery to some extent resembles that of the wilder parts of the Highlands. Rugged hills, crags, and rocky knolls strewn with boulders are the characteristic features of the areas between Criffel and Bengairn, between New Galloway and Cairnsmore of Fleet, and between Loch Dee and Loch Doon. For rugged grandeur, no region in the South of Scotland can compare with the lofty granite plateau which skirts the eastern slope of the Merrick Hills.

A glance at an orographical map of the Southern Uplands shows that the more elevated tracts, ranging from 1000 to 2000 feet in height, extend along the northern and central portions of the tableland, and that only in certain small areas do they exceed this elevation. In the far north-east lie the Lammer-

muir Hills, from 1500 to 1700 feet high, which, on the north, rise with a steep front from the fertile plain of East Lothian, and on the south slope gently downwards into the Merse of Berwickshire. Westwards come the Moorfoot Hills with a greater elevation, forming a natural wall on the south-east margin of the Carboniferous basin of Midlothian. Further to the south-west, in the region between Peebles and Moffat, the characteristic features of a lofty tableland, trenched by deep and narrow valleys, are strikingly displayed. Here are to be found the largest relics of the ancient plateau, rising above 2000 feet; the area round Hartfell (2651 feet) and White Coomb (2695 feet) measuring eleven square miles, and that round Broad Law (2723 feet) six square miles. From this mass of high ground some of the larger streams radiate, the Tweed with some of its tributaries, the Annan, and the Moffat Water. In the upland region between the sources of the Clyde and the Nith, where many affluents of these rivers take their rise, the Lowther Hills are the most prominent group, the highest eminence being the Green Lowther (2403 feet).

West of Nithsdale, though there are marked traces of a highly denuded tableland, intersected by a branching system of valleys, the most prominent physical features are those associated with the granite masses and the altered Silurian sediments in contact with the granite. Of the hills formed by eruptive rocks, reference may be made to Criffel (1866 feet) rising with a steep slope from the shores of the Solway, to Cairnsmore of Fleet (2331 feet) near the Sands of Cree, to Cairnsmore of Carsphairn (2612 feet) near the head waters of the Ken. Still more conspicuous are the lofty parallel ridges of the Merrick and Kells Hills running in a north and south direction, on either side of the Loch Dee granite mass. They are composed of Silurian strata altered by the igneous protrusions, which, on the Merrick (2764 feet), form the highest ground in the South of Scotland.

From the slopes of the Merrick Hills and Cairnsmore of Fleet, westwards to the Portpatrick coast line, the ground falls below the level of 1000 feet save on the heights of Beneraird (1435 feet) at the head of Glen App and other localities. This broad expanse of rough moorland is dotted over with lochs and covered with peat-mosses, moraines, and other glacial deposits, interspersed with rocky hills and knolls.

Of the various watersheds in the Southern Uplands, the most important is that which separates the streams flowing southwards into the Solway from those draining north-westwards into the Firth of Clyde and eastwards into the German Ocean. It is noteworthy that, while this watershed crosses the uplands from the Cheviot Hills, along a highly sinuous line, by the sources of the Tweed and Clyde, yet on reaching the basin of the Nith it leaves the Silurian tableland and traverses for a short distance the Carboniferous lowlands near New Cumnock. From this point it curves round the head waters of the Nith

and passes along the northern portion of the uplands by Loch Doon to Loch Ryan. It is obvious that this watershed must have been determined at a remote geological period when the Silurian uplands were partly or wholly buried under younger Palæozoic rocks.

Of the various river-systems included in the Southern Uplands, one of the largest—the Tweed with its numerous tributaries—flows eastwards into the German Ocean. Here, again, it is interesting to observe that one of its affluents, the Lyne Water, rises on the slopes of the Pentland Hills several miles to the north of the Silurian tableland, and after crossing the Old Red Sandstone plateau at West Linton, enters the uplands near Romanno bridge, and joins the Tweed west of Peebles. The streams draining into the Firth of Clyde are the Clyde, the Doon, the Girvan, and the Stinchar; while those flowing southwards into the Solway Firth include the Esk, the Annan, the Nith, the Dee, the Fleet, the Cree, and the Water of Luce. Many of the latter spring from the heights near the northern margin of the tableland and traverse nearly the whole breadth of the uplands in their southward course. The Nith presents one distinctive feature which is worthy of note, for it rises on the northern slope of the Silurian tableland and flows northwards on to the Carboniferous lowlands near New Cumnock; thence curving round towards the south, it winds its way across the uplands to the Solway.

The valley system just described is indeed a marvellous monument of denudation. It has been carved out of an extensive plateau of Silurian rocks which have been intensely folded and puckered; the drainage system being altogether independent of the curvature of the strata. In the sequel (page 78) it will be shown that, in part at least, it dates back to remote geological periods, for once and again the Silurian rocks have been buried under younger Palæozoic deposits which have been almost wholly removed, save in the Eastern Lammermuirs, Lauderdale, Nithsdale, Annandale, and the basin of Loch Ryan.

Along the northern margin of the tableland, the Silurian strata are bounded by a powerful fault, traced nearly from sea to sea, which lets down the Old Red Sandstone and Carboniferous rocks of the central lowlands. In the south of Ayrshire, near the source of the Stinchar, this dislocation enters the uplands and descends the Water of Muck and Glen App to Loch Ryan, thence across the Corsewall promontory to the Irish Channel. On the south-east side of the uplands from the Merse of Berwickshire, southwards by the Vale of Teviot and Liddisdale to the shores of the Solway, the Silurian rocks are unconformably overlain by Old Red Sandstone and Carboniferous strata, which dip away from the denuded slopes of the old Palæozoic land-surface.

In the following chapter we shall endeavour to show that since the days of Hutton and Hall various sections in the Southern Uplands have become classic ground to geologists

from the evidence which they furnished in support of the Huttonian theory, and further, that, in the closing decades of the present century, these Silurian rocks have become widely known through the researches of Professor Lapworth, who, by the zonal distribution of the graptolites, supplied a clue to the unravelling of the complicated stratigraphy of the whole region.*

* The area occupied by the Silurian strata of the Southern Uplands with the associated granite masses, now uncovered by later Palæozoic rocks, has been estimated by Mr. F. Bosse, of the Geographical Institute, Edinburgh, to be 2584 square miles.

CHAPTER II.

History of Previous Researches among the Silurian Rocks of the South of Scotland.

TOWARDS the close of last century, when Hutton was laying the foundations of physical geology, the Southern Uplands played an important part in establishing the truth of the Huttonian theory. Hutton observed that the tract of schistus mountains, extending from St. Abbs Head to Portpatrick, where the strata are highly inclined or vertical, is flanked on each side of the ridge by nearly horizontal beds, resting on the upturned edges of the older rocks. He contended that the vertical strata of the schistus mountains had been originally deposited as sediment on the sea floor, and that by the action of the earth's internal heat they had been consolidated and elevated so as to form a land-surface. He further held that the vertical schistus had been denuded by natural agencies before the deposition of the horizontal strata, and that the overlying conglomerates, sandstones, and shales are merely the consolidated gravel, sand, and mud derived from the waste of the underlying rocks. In support of these conclusions, he referred to the section of Siccar Point on the Berwickshire coast, which he had visited with his friends Sir James Hall and Professor Playfair in 1788; and also to that in the river Jed south of Jedburgh—the latter being illustrated with a drawing by Mr. Clerk of Eldin—where conglomerates, sandstones, and marls (Upper Old Red Sandstone) rest unconformably on the vertical schistus (Silurian). These views regarding the origin and physical history of the Palæozoic rocks were gradually worked out by Hutton before the publication of his great work in 1795, and are now adopted as fundamental principles of geology.*

In 1792, his generalisations were confirmed in a remarkable manner by the discovery of organic remains in one of the bands of limestone in the Southern Uplands. While riding between Noblehouse and Crook on his way to Moffat, Sir James Hall visited the limestone quarry at Wrae in Peeblesshire, where, among the blocks lately broken off for use, he found shells quite distinct and in great abundance. Regarding the value of such evidence, Hutton remarked, "I have already observed that one single example of a shell, or of its print, in a schistus, or in a stone stratified among these vertical or erected masses, suffices to prove the origin of these

* "Theory of the Earth." Vol. I., pp. 421, 431, 437, 454.

bodies to have been, what I had maintained them to be, water-formed strata erected from the bottom of the sea."*

In his "Mineralogy of Dumfries," published in 1805, Jamieson grouped these older Palæozoic sediments with the Transition Rocks or Grauwacke Series of Werner. He had traced them from the northern extremity of the Pentland Hills to Langrobie in Dumfriesshire about three miles from the Solway Firth. He further states that the same class of rocks reaches from Langholm to Moniaive, terminating near New Galloway, where they give place to primitive strata. The Moorfoots are occupied by Transition rocks, and he had every reason to believe that they extend as far as St. Abbs Head. He gives lithological descriptions of various rocks in the series.

In 1812, an important paper was communicated to the Royal Society of Edinburgh by Sir James Hall, in which he endeavours to account for the remarkable undulations of the greywacke series which had then been proved to extend from the sea-coast of Galloway to Berwickshire. While visiting the shore-sections in Berwickshire in 1788 with Hutton and Playfair, it occurred to him that the folds might be accounted for by supposing that the strata, originally flat, had been subjected to compression by forces acting in opposite directions, under a superincumbent weight that might be upheaved by a powerful exertion. He inferred that when the forces were simple or regular, they would produce simple curvatures. When complicated, or where they acted at successive periods, they may have given rise to abnormal folds. The founder of experimental geology at once proceeded to test his conjectures by experimental methods. He devised a machine whereby pliable beds of clay were pressed together, and thus produced isoclinal and normal folds similar to those at Fast Castle in Berwickshire. His results, figured in the Transactions of the Society, have a special interest in view of recent researches on mountain-building on the Continent, in America, and in Britain.†

Proceeding to consider how the horizontal thrust may have been produced, he suggested that it might be explained by Hutton's original hypothesis, according to which our continents have been raised from the bottom of the sea and elevated to their present position by the internal action of the same heat which shows itself externally in volcanoes.

In this paper also, the author endeavours to account for the convolutions of the schists and greywackes, partly by the intrusion of granite. Subsequent to 1790, he had visited on several occasions the mass of granite to the west of Loch Ken, and had made observations that confirmed his previous conclusions. He describes in considerable detail the nature of the junction between the granite and the schistus from the Hill of Lauren to

* "Theory of the Earth." Vol. I., pp. 334–6.

† Sir James Hall. "On the Vertical Position and Convolutions of Certain Strata and their Relation with Granite." Read 3rd Feb. 1812. Published 1815. Trans. Roy. Soc. Edin. Vol. VII.

New Galloway, indicating the best-marked veins of granite which occur at these localities. He infers that the granite is posterior to the schists, and has flowed into its present position from below upwards, in a liquid state.

After a lapse of more than a quarter of a century, the progress of research among these older Palæozoic rocks was signalised in 1839 by the announcement of further discoveries of organic remains made by Mr. Charles MacLaren and Mr. J. Carrick Moore. The former author, in his volume on the "Geology of Fife and the Lothians," notes the occurrence of an *Orthoceras*, subsequently named *Orthoceras MacLareni*, and fragments which had some resemblance to parts of small trilobites in the greywacke slate near Deerhopefoot, by the side of a small stream that falls into the North Esk in the Pentland Hills. Early in the same year a brief notice was communicated to the Geological Society of London by Sir Charles Lyell on the occurrence of graptolites in the slates of Loch Ryan, Wigtownshire, which had been found by Mr. J. Carrick Moore.*

In 1840 Mr. J. Carrick Moore communicated a paper to the Geological Society of London "On the Rocks which form the west shore of the Bay of Loch Ryan in Wigtownshire," in which he recognises the strata as forming part of the great greywacke chain, which had been coloured in the geological maps of Dr. Macculloch and Mr. John Phillips as a belt stretching from the Irish Sea to St. Abbs Head. He refers to the prevailing strike, the coarse conglomerates with pebbles of igneous rock near Corsewall Lighthouse, and the graptolites occurring abundantly in certain seams.†

In 1841, Professor Nicol's essay "On the Geology of Peeblesshire" appeared in the Transactions of the Highland Society. In his early years he had roamed far and wide over the hills and glens in his native valley of the Tweed, and had discovered graptolites in the Grieston Slates in that county. Following the nomenclature then in vogue, he grouped the greywackes and associated slates with the Transition Series of Werner.‡

In an essay on the Geology of the Stewartry of Kirkcudbright by Mr. R. H. Cunningham,§ published in 1843, a description is given of the different groups of rock which enter into the geological structure of the county. The author notes generally the character of the Silurian rocks with reference to their contortions, but attempts no classification of their different beds. He indicates the representatives of the lower stratified rocks found on the shore, and describes in detail the various masses of granite and their relation to the Transition strata. He calls attention to the occurrence of syenite, porphyry, and trap in various parts of the Stewartry, and alludes to the con-

* "Geology of Fife and the Lothians," 1839, p. 203. "The Occurrence of Graptolites in the Slate of Galloway." C. Lyell. Proc. of the Geol. Soc. Vol. III., p. 28.

† Proc. of the Geol. Soc. Vol. III., p. 277.

‡ Trans. of the High. Soc. Vol. VIII., p. 149.

§ "Geognostical Description of the Stewartry of Kirkcudbrightshire." High. Soc. Trans. (New series.) Vol. VIII. p. 697.

nection between granite, syenite, and porphyry, regarding them as mineralogical varieties which had a contemporaneous mode of formation.

In 1843 Mr. Thomas Stevenson read a paper before the Wernerian Natural History Society "On the Geology of the Island of Little Ross, Kirkcudbrightshire,"* in which he describes the lithological characters of the strata and announces the discovery by Mr. I. T. Syme, C.E., of a shell resembling a *Terebratula*. He also records the discovery by Mr. Fleming, of Kirkcudbright, of an *Orthoceras* in the Silurian rocks on the mainland opposite to Little Ross Island.

In 1844, appeared Professor Nicol's "Guide to the Geology of Scotland," in which he makes the following statement with reference to the strata of the Silurian tableland: "Fossils are so extremely rare in all this series of rocks that they furnish almost no assistance in classifying them. Graptolites and a few shells have been found in Kirkcudbrightshire and Peeblesshire, and some obscure vegetable impressions in Roxburghshire: but these are the whole amount, and hardly serve to connect this formation with the Transition rocks of England, far less to enable us to arrange the various beds in their true order. It is usual to consider this whole series as synchronous with the older Silurian rocks of Murchison."†

In 1848, a marked advance was made by Professor Nicol, in a paper "On the Geology of the Silurian Rocks in the Valley of the Tweed," in which he correlates the strata on palæontological grounds with Murchison's Silurian formation of Wales, and gives the first general description of the succession of the rocks. He observes that, in tracing the formation from Peebles and the Lothians, through Selkirk and Roxburgh to the confines of England, the coarser beds predominate in the north, while the finer-grained rocks prevail in the south. He infers that the materials may have been derived from the north and deposited in a sea becoming deeper to the south. From the constituents of the sediments, he concludes that they may have been derived from the North of Scotland.

Of special interest is Nicol's description of the rocks associated with the Wrae Limestone. The quarry having been abandoned, he was unable to estimate the thickness of the limestone, but he states that it is covered by blue slate in which he found angular nodules of limestone from an inch to several feet in diameter. In the slate he found no organic remains; but the masses of limestone are full of them, appearing therein as a crystalline mass of encrinite stems. A list of fossils, with notes by Mr. Salter, is appended, who was then inclined to regard the strata as of Lower Silurian age.‡

In this paper also, a suite of fossils, collected by Mr. Fleming from the rocks on the shore south of Kirkcudbright and trans-

* Edin. New Phil. Jour. Vol. XXXV., p. 83.
† "Guide to the Geology of Scotland." Pages 28-29. 1844.
‡ Quart. Jour. Geol. Soc. Vol. IV., p. 195.

mitted by Lord Selkirk to the Geological Society of London, is named by Salter. He concludes that "on the whole the fossils appear to be of the date of the Wenlock Shales."

While Nicol was thus exploring the central portion of the tableland, Mr. J. Carrick Moore was extending his observations along the western margin. In a paper "On some Fossiliferous Beds in the Silurian Rocks of Wigtownshire and Ayrshire," contributed to the Geological Society of London (read May 17th, 1848, and published in 1849),* the author describes the general characters of the Silurian strata from the Mull of Galloway to Corsewall Point, indicating various localities where graptolite shales occur (Cairn Ryan, Dally Bay, etc.), and giving a horizontal section. He further makes the important announcement of the discovery of a band of fossiliferous limestone which he had observed at five localities along the course of the valley of the Stinchar (the Stinchar Limestone).

A note by Salter, on the fossils from the limestone of the Stinchar and the slates of Loch Ryan, is appended, in which he states that the former are decidedly of Lower Silurian age, and that he would identify them at once as belonging to the same epoch, if not to the same bed, as those of the Wrae Limestone in Peeblesshire. A list of fossils from the limestone is given and specimens are figured, including the first notice of the genus *Maclurea* in Britain.

In 1849, Professor Nicol, having made traverses over a great part of the Southern Uplands, communicated a further paper to the Geological Society "On the Silurian Strata of the South-east of Scotland."† Graptolites from Grieston and Thornilee are recorded, and several examples are figured for the first time from that region. He states "that from the whole facts noticed in this and a former paper, there can be little doubt that the slates and greywackes of this part of Scotland belong to the Lower Silurian period, and are probably the equivalents of the Llandeilo flags of Wales."

From the stratigraphical relations of the strata, Nicol infers that "in this part of the chain there is an anticlinal axis over which the beds have been folded. Taken generally, this axis will pass from the group of felspar-porphyry hills east of Innerleithen to Loch Skene, north of Moffat."

In 1850, a further advance was made in the investigation of these Silurian rocks by Professor Harkness, who, in his native county of Dumfries and in the adjoining county of Kirkcudbright, had studied their development.‡ The results of his researches were embodied in a paper contributed to the Geological Society of London. The author describes generally the strata entering into this formation; indicating in particular three parallel bands of anthracitic or black shales which he had

* Quart. Jour. Geol. Soc. Vol. V., p. 7.
† Quart. Jour. Geol. Soc. Vol. VI., p. 53.
‡ "On the Silurian Rocks of Dumfriesshire and Kirkcudbright." Quart. Jour. Geol. Soc. Vol. VII., p. 46. Pub. 1851.

traced for miles; (1) Hartfell, Greskine, &c., (2) Dobb's Linn, Frenchland Burn, &c., (3) Selcoth Burn and Craigmichan Scaurs. He regards them as repetitions of the same band due to a series of parallel faults which might probably account for the prevalent N.N.W. dip of the strata.

After referring to the existence of Wenlock Shales at Kirkcudbright and their fossils, Harkness proceeds to describe the inclinations of the strata between Kirkcudbright and Lockerbie. He infers that an anticlinal axis traverses the range near its southern extremity, and suggests that it may have resulted from the granite eruption of Criffel.

Towards the close of 1850 Professor Harkness communicated to the Geological Society a description of the Upper Silurian strata on the east side of Kirkcudbright Bay, including the graptolitic flagstones and soft grey shivery shales with limestone nodules.* He refers to the graptolites occurring in profusion in certain bands and to the orthoceratites, and states that the general character of the fossils in the deposits about Balmae is such as to indicate an intimate relation between the Wenlock Shales and this portion of the Silurian series. A description of the graptolites from the black shales of Dumfriesshire, which had been submitted by Professor Harkness to M. Barrande and Mr. Salter, is appended to this paper.

From the statements made in the foregoing paragraphs it is clear that some progress had already been made in the exploration of the rocks of the Silurian tableland, chiefly through the researches of Nicol, Carrick Moore, and Harkness, aided by the Silurian palæontologist Salter, when in 1850 Sedgwick and Murchison, with the knowledge gleaned from a prolonged study of the Silurian and Cambrian rocks of Wales, endeavoured to correlate the old Palæozoic rocks of the South of Scotland with their probable equivalents in the Welsh Principality.

In 1850, Professor Sedgwick communicated a paper to the meeting of the British Association in Edinburgh "On the Geological Structure and Relations of the Frontier Chain of Scotland."† Having crossed the chain in 1841 with Mr. J. Carrick Moore, and having made further traverses in 1848 with the hope of determining (on the principles laid down by Professor Rogers) the line from which the undulations had originated, Sedgwick arranged the strata in five successive groups in ascending order:

1. A group of hard arenaceous beds always in a highly inclined position, in which a pyritous alum schist abounds, extending from Lockerbie to the neighbourhood of Moffat. The alum slates are crowded with graptolites.
2. A great arenaceous group with bands of earthy flagstone

* Quart. Jour. Geol. Soc. Vol. VII., p. 54. Read Dec. 4, 1850.
† Brit. Assoc. Rep. for 1850. Trans. Sects., p. 103. And Edin. New Phil. Jour. Vol. LI., p. 250.

and coarse slate, part of which is well exposed in the railway cuttings north of Moffat. This series extends into Peeblesshire and the upper parts of the valley of the Tweed, and thence to St. Abbs Head. Some calcareous bands, associated with very coarse conglomerates, appear in this group north of Peebles, and a well-defined bed of limestone is seen at Wrae and Drummelzier.

3. South Girvan group, comprising the Stinchar Limestone and associated conglomerates, together with the strata forming the plateau between the valleys of Girvan and Stinchar and visible on the shore south of Girvan.

4. North Girvan group, the members of which constitute the Craighead "inlier" north of the Girvan valley. It includes the Craighead Limestone, which is associated with a great mass of trap, shelly sandstones, with shales and flagstones containing numerous trilobites.

5. Balmae group. The members of this sub-division bound the south-east extremity of Kirkcudbright Bay, and are composed of thick-bedded greywacke alternating with flagstone in thin beds together with thick masses of indurated slate. Some of the beds contain numerous graptolites, while the calcareous concretions are associated with corals, orthoceratites, and shells.

In the concluding remarks to his paper, Sedgwick states that the lowest fossils in the chain appear to be graptolites. The South Girvan group is compared with the Bala and Coniston Limestone, while the North Girvan group is correlated with the grits and shelly sandstones that overlie the Llandeilo Limestone. Finally, he expresses his belief that, while the Grampians had probably their greatest elevation after the period of the Old Red Sandstone, the principal elevations of the frontier chain (Southern Uplands) were produced before the deposition of the Old Red Sandstone.

A list of organic remains, collected by Sedgwick in the course of his traverses and determined by Professor M'Coy, is appended to this paper.

In 1850 also, Sir Roderick Murchison made a series of traverses across the Silurian tableland, accompanied by Professor Nicol, and during part of the time by Professor Harkness. Having visited, at various periods, portions of the Southern Uplands, he had a strong desire to examine the rocks more closely, as they had been referred by others to the Silurian system. He was further stimulated to pursue his investigations by Sedgwick's verbal communication to the Geological Section of the British Association at Edinburgh on the highly fossiliferous rocks near Girvan. A large collection of organic remains was obtained in the course of these traverses, which was subsequently determined by Mr. Salter. The results of these observations were embodied in an elaborate memoir, published in the Quarterly Journal of the Geological Society in 1851. A list of Silurian fossils from Ayrshire, with descriptions of some

of the special types, was appended, together with a geological sketch map of the coast of Carrick, Ayrshire.

The rocks constituting the Silurian series of Ayrshire are arranged by Murchison in the following descending order:

3. Schists and flagstones (orthoceratites).
2. Shelly greywackes, sandstones with conglomerates (Caradoc and Llandeilo).
1. Limestone and schist (Lower Llandeilo).

The orthoceratite flags and graptolite schists of Piedmont, Ardwell, and Penwhapple Burn, forming the highest subdivision, are represented as occupying a syncline on the south side of the Girvan valley; the beds being traceable from the shore at Ardwell eastwards to Penwhapple Glen. They are mapped as resting on the grits of Saugh Hill and the coarse conglomerates of Kennedy's Pass. Again, on the north side of the Girvan valley, he refers the shelly sandstones of Mulloch Hill to his middle group, and the trilobite shales of Drummuck to the upper division. The lower group includes the limestones of Stinchar, Tormitchell (Tramitchell), and Craighead, being brought to the surface by a series of axial folds. He, however, calls attention to a suggestion of Professor Nicol's that the shelly sandstones of Saugh Hill (Group 2) may overlie the orthoceratite flags (Group 3). Reference is made to the great series of igneous rocks so prominently developed in certain areas.

Regarding the structure of the Southern Uplands generally, Murchison accepts the view that a powerful anticlinal arch passes somewhere near Dumfries, and north-east by Lockerbie; but owing to the extraordinary folding of the strata, he found it difficult to arrive at a reliable order of succession. He, however, made an important suggestion, that the three bands of anthracite shales traced by Professor Harkness may be repeated by folds rather than by faults; the upper parts having been removed by denudation. Murchison clearly saw that, whatever be the exact place of the graptolite shales in the Silurian series, the recognition of their being repetitions of one band, by means of folds, formed an important step in limiting the thickness of the strata.

Regarding the age of the beds of the central chain, Murchison states that it is difficult to decide the question, since there are scarcely any other fossils than graptolites and certain obscure orthoceratites with annelida in the schists of Dumfriesshire. He considers that Harkness, in viewing them as an upper portion of the Lower Silurian rocks, places them rather high in the series. He suggests that "they probably represent that great mass of Welsh schist which underlies the Llandeilo or Bala Limestone, but is still superior to the lowest zone of Silurian life."

With reference to the strata at Balmae Head, Kirkcudbright, Murchison accepts the conclusion arrived at by Salter from a

determination of the fossils, that these beds could not be older than the Wenlock Shales.

In 1852, Professor Nicol announced the results of his detailed researches among these Silurian rocks, giving a horizontal section drawn across the chain from the Pentlands to the Cheviots.

Continuing his traverses in the South of Scotland, Professor Harkness stated in 1852 that he had traced the anthracite bands of Dumfriesshire through the greater part of Selkirkshire to the neighbourhood of Galashiels.* He no longer referred the Silurian rocks of Dumfriesshire to Caradoc time as in his former memoir, but regarded them as lying below the representatives of the Llandeilo flags, as suggested by Murchison. A note by Salter, descriptive of some graptolites collected by Harkness from the South of Scotland, precedes this paper.

The first detailed description of the Upper Silurian rocks of the Kirkcudbright shore was given by Professor Harkness in 1853. The strata from Netherlaw Point to Balmae Head are classified by him in three groups: 1, Shale and sandstone at the top; 2, Greywacke sandstone; 3, Indurated black shales with graptolites. A prominent sub-division of the highest group consists of grey shales with fossiliferous calcareous nodules, alternating with light grey ripple-marked sandstones. From Group 3 he obtained *Graptolithus priodon*, *G. Flemingii*, and orthoceratites. He mentions the occurrence at Coal Heugh, near Barcaple, of anthracite bands (black shales) which connect the rocks in the Dee with the lowest beds in the Silurian system. The results of his observations are embodied in the following general conclusion: that we have in this portion of the Stewartry (1) certain deposits representing the Llandeilo flags, (2) conglomerates and sandstones which may be regarded as the representatives of the Caradoc Sandstone, and (3) a higher series of beds (Balmae beds) which are the equivalents of the lower portion of the Upper Silurian rocks.

The discovery by Dr. Slimon of beautifully preserved crustaceans in the Silurian rocks of the Lesmahagow district resulted in important additions to our knowledge of the "inliers" of these strata in the midst of the Old Red Sandstone of Lanarkshire. Accompanied by Sir Andrew Ramsay and Dr. Slimon, Murchison visited that district and examined the sections in the Logan Water where the fossils had been found. The results of these traverses were embodied in a paper contributed to the Geological Society in 1855,† in which Murchison states that the dark fossiliferous shales exposed in the Logan Water pass conformably upwards into the Lower Old Red Sandstone of that district. A horizontal section is given

* "On the Silurian Rocks of the South of Scotland and on the Gold Districts of Wanlockhead and the Leadhills." By R. Harkness. Quart. Jour. Geol. Soc. Vol. VIII., p. 393.

† "On the Discovery by Mr. Robert Slimon of Fossils in the Uppermost Silurian Rocks near Lesmahagow, in Scotland, with Observations on the Relations of the Palæozoic Strata in that part of Lanarkshire." Read Nov. 1855. Quart. Jour. Geol. Soc.

showing the relations of the Upper Silurian strata to the Old Red Sandstone. He further points out that Salter had detected in Mr. Slimon's collection sculptured plates of crustaceans similar to those which had been hitherto referred to *Pterygotus*, together with the small *Lingula cornea* and *Trochus helicites* of the uppermost Ludlow Rock of Wales. These are associated with five or six new forms which Salter termed *Himantopterus*, and fragments of *Ceratiocaris*.

Appended to this paper is a description by Salter of some new crustacea from the uppermost Silurian rocks of the Lesmahagow district, and a note by Professor Huxley on the structure and affinities of *Himantopterus*.

In 1855, a description of the section in Glenkiln Burn, Dumfriesshire, was published by Professor Harkness, special reference being made to the anthracite shales which occur at this locality, and to the Barlae flags north of Dalry, Kircudbrightshire.* The author places the Barlae flags on the same horizon with the Grieston Slates. A list of fossils, with notes, is appended to this paper.

In 1856, Professor Harkness communicated to the Geological Society a paper "On the Lowest Sedimentary Rocks of the South of Scotland." He therein indicates the position of the great anticline, the nature of the axial beds, and the fossils obtained from them. He abandons the theory that the parallel bands of black shales are repeated by faults, and adopts Murchison's view that they are due to folds. He announces the discovery of a species of *Olenus* at Corfarding, near Penpont, Dumfriesshire.† (See p. 347.)

In the same year, a suggestive communication was contributed by Mr. Carrick Moore to the Geological Society, in which special reference is made to the system of folding in the Silurian rocks of Wigtownshire. He calls attention (1) to the peculiar arrangement of the strata from Corsewall Point to within six or eight miles of the Mull of Galloway. Along this line the rocks are bent into a series of anticlinal and synclinal folds which are thrown over to the north, the axes of the curves dipping to the south. He points out that the structure here described is similar to those inversions of rock in the north of Germany, in the Ardennes, the Eifel, and to those of the Appalachian chain in the United States. He further suggests that there are many reasons for believing that all the principal movements which these Silurian rocks have undergone had been impressed on them previously to the intrusion of the granites. (2) From the evidence supplied on the shore section between Corsewall Point and Dally Bay and also along the east shore of Loch Ryan, he infers that the coarse conglomerates of South Ayrshire are superior to the schists with graptolites.

In a paper contributed to the Geological Society of London

* "On the Anthracite Schists and the Fucoidal Remains in the Lower Silurian Rocks of the South of Scotland." Quart. Jour. Geol. Soc. Vol. XI., p. 468.

† Quart. Jour. Geol. Soc. Vol. XII., p. 238.

in 1857, Professor Wyville Thomson described and figured some species of *Acidaspis* from the Lower Silurian beds in the Girvan district. He advanced a different order of succession from that of Murchison, holding that the whole of the fossiliferous beds of Girvan belong to the very top of the Lower Silurian system; the Penwhapple flagstones being the lowest of the series, and graduating upwards through the Mulloch Hill Sandstones and the Craighead Limestone into the Saugh Hill grits.*

From the autumn of 1854, when the late Sir Andrew Ramsay, as Director for Great Britain, first began the detailed Geological Survey of Scotland in Haddingtonshire, down to 1867, when the Scottish staff was reorganised and enlarged, with Sir A. Geikie as Director for Scotland, the officers of the Survey (A. Geikie, J. Young, J. Geikie, B. N. Peach) had completed the examination of considerable portions of the Silurian tableland in the counties of Haddington, Berwick, Edinburgh, Peebles, Lanark, and Ayrshire. The results of these detailed researches appeared in the geological maps and in the memoirs descriptive of the respective sheets. In Sheet 32 the various "inliers" of Upper Silurian strata in the Pentland Hills were delineated by A. Geikie, and their relations to the sub-divisions of the Lower Old Red Sandstone were defined. The existence of Ludlow Rocks was then clearly established, which pass, as at Lesmahagow, conformably upwards into the Lower Old Red Sandstone. In the memoir accompanying Sheet 32 (published in 1861), sketch sections are introduced by Sir A. Geikie showing the relations of the strata in the North Esk river and at the south end of the Pentland chain. It is stated that the section in the North Esk is on the whole an ascending one, though showing minor folds. In the Appendix to the memoir the fossils, numbering about forty species, are named and described by Salter, who likewise gives valuable comparative notes on the Upper Silurian strata of the Pentland Hills and Lesmahagow areas.

In 1863, the memoir descriptive of the Geology of Eastern Berwickshire, by Sir A. Geikie, and in 1866 that descriptive of the Geology of East Lothian, by the same author, appeared. The Silurian rocks of these areas are referred to the lower division of the system, the marked convolutions of the strata, especially on the Berwickshire coast line, are portrayed, and various new localities for graptolites are recorded. Special reference may be made to the discovery of *Graptolithus priodon* at Siccar Point, near Cockburnspath, and at Ellemford on the Whiteadder, below Longformacus. The following statement, made by such an eminent palæontologist as Salter, is significant as showing how the zonal value of graptolites was not then clearly recognised. "At present all that can be certainly affirmed is that the rocks are of Lower Silurian age. Though the *Graptolithus priodon* is a Middle and Upper Silurian

* Quart. Jour. Geol. Soc. Vol. XIII. p. 206.

species in England and Wales, it is plentiful at Grieston, near Innerleithen, on the Tweed, in company with *G. Sedgwicki* and other Lower Silurian fossils."*

At a later date, Sheets 7 and 14 of the one-inch maps, with their accompanying explanations (A. Geikie, J. Young, J. Geikie, B. N. Peach), were published. In Sheet 7, embracing the region bordering the coast between Glen App and Girvan, Ayrshire, the order of succession advocated by Murchison was generally adopted. The strata of the Ballantrae region were supposed by Professor James Geikie to exhibit certain arrested stages of metamorphic action, so that we can in many instances begin with unaltered beds and trace the gradual changes which they undergo during their passage into crystalline and pseudo-igneous rocks. The strata cited in illustration of these phenomena embrace (a) felspathic rocks, (b) dioritic rocks, (c) serpentine and altered limestone. The geological history of this intricate region will be given in subsequent chapters (XIX. and XX.)

In Sheet 14 and its accompanying explanation, the anticlinal arrangement of the strata forming the Craighead inlier on the north side of the Girvan valley is clearly portrayed by Sir A. Geikie. The beds forming the core of the arch, comprising the Craighead Limestone and associated strata, which graduate upwards into the Drummuck mudstones, are regarded as of Caradoc age; while the overlying strata, composed of the Mulloch Hill conglomerate, with sandstones, grits, shales, and conglomerate bands, are grouped with the Lower Llandovery formation. Lists of fossils from the Craighead Limestone, then supposed to be of Caradoc age, and the Lower Llandovery Rocks of Kirk Hill, are given. The strip of Silurian strata extending from Straiton to the hills overlooking Kilkerran is revealed for the first time, and though no definite age is assigned to the latter, the beds are described as having a much less ancient aspect than others in the neighbourhood.

In the course of the Geological Survey of Ayrshire a large collection of organic remains was obtained, which were determined by the palæontologists of the Survey and Professor Young. This list was subsequently published as an appendix to the explanation of Sheet 3, one-inch.

As the officers of the Survey carried their geological lines north-eastwards along the northern margin of the Silurian tableland into Lanarkshire prior to 1867, the Upper Silurian inliers of the Hagshaw Hills and Logan Water were mapped in detail by Mr. B. N. Peach. Various sub-divisions were established and a rich suite of organic remains was collected which confirmed the conclusion previously arrived at by Sir Roderick Murchison and Mr. Slimon regarding the age of the beds.

In 1865, Mr. George C. Haswell published a small volume "On the Silurian Formation in the Pentland Hills," in which he describes the geographical position of the Silurian rocks and

* The Geology of East Lothian, p. 71.

their relation to other representatives of the same system in Scotland. He records, describes, and figures about fifty-five species of fossils from various localities in that chain, giving a Table showing their vertical range in the Silurian system. He finds that fifteen species in his list occur in the Ludlow Rocks, fifteen in the Wenlock group, and nineteen in rocks older than the Wenlock. There are ten species which are never found higher up than the Wenlock group, and there are five species which range from the Ludlow group upwards.

In 1867, a paper "On the Silurian Rocks of the Pentland Hills," by Messrs. John Henderson and D. J. Brown, was communicated to the Geological Society of Edinburgh, embodying the results of their observations in the field, and their views regarding the age of the fossiliferous zones which they had carefully searched. A geological map with horizontal sections was published with Part II. of this paper, read to that Society in 1869. Their conclusions may thus be briefly summarised: (1) That, to take the North Esk section as a basis of classification, the strata exposed in the lower part of the river course are of Wenlock age, their northern limit being marked by Bed E in their map, crossing the Esk about half a mile to the north of the reservoir. (2) That the beds to the north of this boundary line are of Ludlow age. (3) That the red beds, marked as the conformable portion of the Lower Old Red Sandstone in the Lyne Water by the Geological Survey, are likewise of Ludlow age, and can be traced across the intervening heights to the North Esk section. (4) That the Silurian rocks in the Lyne Water to the north of the red beds are of Ludlow age. This paper is accompanied by an elaborate Table of fossils, giving the vertical range of upwards of one hundred species of different classes. Of the Brachiopoda, numbering twenty-five species, which were determined by Mr. Davidson, twenty species are found in Wenlock strata, and ten pass up into the Ludlow Rocks.

In connection with the literature bearing on the Upper Silurian rocks of the Pentland Hills and Lanarkshire, reference must be made to the description by Mr. Thomas Davidson of the Brachiopoda from these beds, published by the Geological Society of Glasgow.* This description, accompanied by figures of many of the typical forms, was based on the examination of several thousand specimens from the Pentland Hills which had been collected by Messrs. Haswell, Henderson, and Brown, as well as of those in the possession of the Geological Survey. The author states that he revisited the latter locality in 1866 with Messrs. Haswell and Brown, and that he agreed with the views announced by Messrs. Brown and Henderson as to the age of the beds under description.†

* "On the Upper Silurian Brachiopoda of the Pentland Hills and of Lesmahagow, in Lanarkshire." Trans. Geol. Soc. Glasgow. Part I.

† Further references to palæontological researches relating to the Upper Silurian rocks of the Pentland Hills, including those by Professor Lapworth on Graptolites from Habbie's Howe and by Mr. Laurie on the Eurypterids of Gutterford Burn, will be subsequently given in the section dealing with the structural relations of the beds.

In 1867, the fourth edition of "Siluria" appeared, in which Murchison summarised his views regarding the Silurian rocks of the Southern Uplands, and availed himself of the detailed observations by the Geological Survey in Ayrshire and the Pentland Hills prior to that year. The highest sub-division of the Girvan sequence is now grouped with the Llandovery Rocks; in other points he follows generally the order of succession propounded by himself in 1850. Regarding the Upper Silurian rocks of the Pentland Hills, it is stated, on the authority of Sir A. Geikie, that while the upper part of the Pentland section may be considered as of Ludlow age, it is evident that there is room for a representation of the Wenlock series, which is rendered probable by the number of Wenlock species which have been obtained from these rocks.

In 1867, a clear summary was given by Sir Archibald Geikie of the results of all previous investigations regarding these ancient Silurian rocks.* To the student of historical geology this contribution serves a useful purpose, because it enables him to focus the knowledge then ascertained. The author points out that, owing to the contorted and broken nature of the rocks, it is by no means an easy task to reduce them to a satisfactory order of succession. The labours of Murchison, Sedgwick, Harkness, and Nicol had shown that, viewed on the great scale, the Silurian belt may be regarded as a long arch, of which the centre, running parallel with the length of the chain, is composed of the lowest and oldest strata, while the outer portions consist of higher members of the series dipping away from the central axis towards the margin of the belt. This axis, running in a north-east and south-west direction, crosses the valley of the Annan south of Beattock.

The order of succession then ascertained is given, and the results are thus summarised: With the exception of a comparatively small area in Ayrshire, where Llandovery Rocks appear, and other districts in Kirkcudbright, Lanarkshire, Ayrshire, Peeblesshire, and Midlothian, where Ludlow and Wenlock Rocks have been identified, the whole of the Silurian Uplands of the South of Scotland consist of grits, greywackes, conglomerates, shales, dark schists, and inconstant bands of limestone representing the Caradoc and Llandeilo Rocks of Wales.

In 1868, while the Geological Survey was in progress within the Silurian belt, in the counties of Lanark and Dumfries, Mr. R. L. Jack, in mapping the Leadhills district, discovered certain fossiliferous conglomerates (Duntercleuch and Glendowran) which, from their organic remains, were regarded as of Caradoc age. They seemed to rest on black shales, yielding graptolites of a Llandeilo facies. Though minor folds were recognised in that area, the strata were viewed as forming in the main a great synclinal trough, the Caradoc Rocks occupy-

* Trans. of the Geol. Soc. of Glasgow. Vol. III., p. 74.

ing the centre, and the Llandeilo Rocks coming to the surface on either side.

The subsequent extension of the field work towards Moffat, Eskdalemuir, and Melrose, and south-westwards towards the shores of the Solway and the Irish Sea, by B. N. Peach, R. L. Jack, J. Horne, H. M. Skae, C. R. Campbell, and D. R. Irvine, led the Survey to adopt the following order of succession. Accepting the view that the lowest beds are exposed along the axial line between Dumfries and Eskdalemuir, the strata were arranged in ascending groups as the observer passes northwards to the Leadhills area:—1, The Ardwell group ("Hawick Rocks"); 2, The Moffat black shales; 3, Queensberry grits; 4, Dalveen group; 5, Lowther shales; 6, Upper or Leadhills black shales; 7, Carsphairn group. These sub-divisions of the Llandeilo Rocks were believed to be succeeded by fossiliferous grits and conglomerates (Duntercleuch, &c.) of Caradoc age, apparently, in certain sections, transgressing the underlying sediments. The Wenlock beds, occurring along the southern margin of the great tableland, were supposed to rest unconformably on the Llandeilo Rocks. While it was recognised that the higher bands of the Moffat black shales, and indeed that certain shales in the overlying Queensberry grit series yielded graptolites which elsewhere are characteristic of Llandovery Rocks, the apparent sequence of beds from the Moffat black shales to the Leadhills black shale series was assigned to the Llandeilo formation.

The palæontological anomalies involved in this reading of the order of succession seemed to be satisfactorily explained by Barrande's doctrine of Colonies. That distinguished palæontologist contended that in the Bohemian area, while there existed in the Silurian strata a normal sequence of organic remains similar to that of other regions, there were certain bands charged with the fossils of a higher zone which occurred on different horizons in a lower portion of the system. These bands were termed colonies; the occurrence of which he explained on the supposition that the younger fauna had already appeared beyond the limits of the Bohemian area, and for a time gained access to that region before the final disappearance of the older fauna.

Applying this generalisation to the rocks in the South of Scotland, it was held that those graptolites which are found in the higher bands of the Moffat black shales and rarely in the series of Queensberry grits, though elsewhere characteristic of Llandovery Rocks, might be precursory forms, which gained access to the region during the deposition of the Lower Silurian sediments. Just as Barrande maintained that, in the Bohemian area, graptolites characteristic of the third fauna (Upper Silurian) appear in bands, intercalated at intervals in strata replete with the second fauna (Lower Silurian); so it was believed that, in the South of Scotland, the Llandovery graptolites of the Moffat region might be precursory forms

which lived for a time and then disappeared, while the Lower Silurian graptolites reappeared and flourished during the deposition of the upper or Leadhills black shales.*

The sequence adopted by the Survey seemed to find some support in the remarkable change in the character of the sediments when passing northwards from Eskdalemuir by Moffat to the Leadhills area. The Ardwell beds ("Hawick Rocks") differ from the normal type of the Queensberry grit series, while the Lowther shales can be readily distinguished from both the preceding groups.

On the other hand, it must be frankly admitted that the Geological Survey encountered great difficulties in their reading of the sequence. For example, in the continuous coast sections at the mouth of the Dee in Kirkcudbrightshire, no trace of an unconformity or a fault could be found between the Wenlock strata and the Ardwell beds, though, according to the views then held, such a discordance ought to occur.

The researches of Professor Lapworth, extending over many years, among the Silurian rocks of the South of Scotland, eventually furnished a complete solution of these stratigraphical and palæontological difficulties. After a prolonged study of the vertical range and distribution of the graptolites, he discovered the clue to unravel the complicated stratigraphy of the whole region. In the following pages we endeavour to give a historical sketch of the development of his researches from his earliest observations in the neighbourhood of Galashiels to the publication of his final contribution relating to the stratigraphy and palæontology of the Southern Uplands.

In 1870, Professor Lapworth published a paper "On the Silurian Rocks of the neighbourhood of Galashiels," in which he arranges the strata in two groups (a) the black shales of the Moffat series, (b) the Gala group.† He infers (1) that there are two distinct and characteristic faunas in the district, one peculiar to the black shales and the other to the Gala group. (2) That the upper fauna is pre-eminently of the Coniston or Bala type. Hence the Gala group may collectively be considered as a thick and almost inseparable series of greywackes and shales superior to the Moffat series, and of Caradoc age.

In 1871, a conjoint paper by Professor Lapworth and Mr. J. Wilson "On the Silurian Rocks of the Counties of Roxburgh and Selkirk"‡ was read before the Geological Section of the British Association at Edinburgh and published in the Geological Magazine. The strata are arranged in five groups, named from the districts where they are best developed, given

* Barrande. *Défense des Colonies* v. *Apparition et reapparition en Angleterre et en Ecosse des espèces Coloniales Siluriennes de la Bohême.* 1881.
Sir A. Geikie. Text-book of Geology. First ed., 1882, p. 629.
B. N. Peach. Proc. Roy. Phys. Soc. Vol. IX., p. 8.

† Trans. Edin. Geol. Soc. Vol. II., p. 46.
Geol. Mag. 1870, pp. 204-209 and 279-284.

‡ Brit. Assoc. Rep. for 1871.
Geol. Mag., 1871 p. 456.

here in ascending order:—1, The Hawick Rocks; 2, The Selkirk beds; 3, The Moffat Series; 4, The Gala Group; 5, The Riccarton beds.

Following previous investigations, the oldest rocks are supposed to come to the surface along the axial line extending from Berwick to Dumfries, being succeeded towards the north by higher groups in natural sequence. The important statement is made that there is but one band of black shales in the whole region lying at the top of the Moffat Series, which plunges underneath the Gala Group and reappears along the northern edge of the Silurian tableland.

To the south-east of the great anticline the Selkirk beds follow the Hawick Rocks; while the former are succeeded by the Riccarton beds, which are of Upper Silurian age. Five separate areas are indicated where these Upper Silurian strata occur: (1) To the south of Kirkcudbright, (2) to the south of the granite area of Criffel and Dumfries, (3) in the region stretching from a point near Lockerbie to the Old Red Sandstone near Stobs Castle, (4) in a large "inlier" surrounded by Old Red Sandstone and Carboniferous strata reaching from the village of Oxnam, near Jedburgh, to Arnton Fell on the Liddel, (5) in a small patch at the head of the Kale Water high up among the porphyries and limestone of the Cheviot Hills.

The northern boundary of the Upper Silurian rocks seems to form nearly a straight line parallel with the average strike of the Lower Silurian strata. Though unable to prove it, the authors suggest that this boundary may be a fault.

A careful comparison of the Moffat graptolites with those of other countries convinced the authors that these beds should be classed with the Utica Slate and Hudson River Group of North America and the graptolite-bearing schists of Wexford and Waterford; in other words, that they are of Bala age or bridge over the gap between the Bala and Llandeilo formations.

The fossils of the Gala Group led the authors to place it high among the Lower Silurian rocks, and indeed to believe that some of the high beds might be of Upper Silurian age. Its fauna approximates most closely to that of the Coniston mudstones of Cumberland and Westmoreland.

At the same meeting of the British Association Mr. D. J. Brown read a paper "On the Silurian Rocks of the South of Scotland."* In a section drawn from Moffat Water in Dumfriesshire to Kilbucho in Peeblesshire, the author considers that the rocks form two series: a lower Moffat or Llandeilo and an upper or Caradoc series resting unconformably on the lower. This view of the unconformable relation of these groups is advocated in a series of papers by Mr. Brown published in 1873 and 1874 in the Transactions of the Geological Society of Edinburgh.†

* Brit. Assoc. Rep. Trans. of Sections, p. 93.
† Trans. Geol. Soc., Edin. Vol. II., pp. 227, 316, 377.

In 1872, Professor Lapworth advanced a comprehensive classification of the Silurian rocks of the Southern Uplands.*

Still accepting the great anticline between Berwick and Dumfries exposing the lowest strata, the author arranges the strata in the following order:

A. *Lower Silurian.*

1. Hawick and Selkirk beds, .	Cambrian. Skiddaw.
2. Moffat Shale or Anthracite—	
(a) Lower Anthracite, .	Lower Llandeilo.
(b) Middle Anthracite, .	Upper Llandeilo.
(c) Upper Anthracite, .	Lower Caradoc.

B. *Middle Silurian.*

1. The Gala Group, Girvan Series,	Upper Caradoc.
Duntercleuch beds, Wrae beds,	Lower Llandovery.
&c., ...	Upper Llandovery.

C. *Upper Silurian.*

1. The Balmae and Riccarton beds,	Wenlock and Lower Ludlow.
2. Lower Pentland beds, .	Wenlock.
(b) Upper Pentland beds, .	Ludlow.
(c) Pentland Sandstone, .	Passage beds and Downton Sandstone.

The Appendix contains lists of fossils from the various zones.

In 1872, Mr. Hopkinson, whose researches among the Silurian graptolites are well known, described in the Geological Magazine† some new forms of graptolites from the South of Scotland. In accordance with the previous researches of Professor Lapworth the author states that from the evidence afforded by the fossils it seems more probable that only one band of graptolite shale runs through the Llandeilo Rocks of the South of Scotland, there being in this band several distinct zones, each marked by a different assemblage of fossils, but with many species in common.

During the same year Professor Lapworth, in a paper contributed to the Geological Magazine "On the Results of some recent Researches among the Graptolite Black Shales of the South of Scotland,"‡ states that subsequent researches had clearly proved the correctness of his main conclusions as published in 1871, which are thus summarised:

There is but a single group of black shale, from 500 to 600 feet in thickness, named the Moffat Shale. This group is lithologically and palæontologically separable into three great

* "On the Silurian Rocks of the South of Scotland." Trans. of the Geol. Soc. of Glasgow. Vol. IV., p. 164.
Geol. Mag., May 1872.

† Geol. Mag., 1872. Vol. IX., p. 501.

‡ Geol. Mag. Vol. IX., p. 533.

divisions: the Lower, Middle, and Upper Moffat. The Lower division contains the graptolites of the Hudson River Group of America and of the Llandeilo beds of Portmadoc, and is probably of Lower Llandeilo age. The Middle Moffat appears to be the equivalent of the Upper Llandeilo of Builth, while the Upper Moffat is decidedly Caradoc. The Moffat Shale, which in almost every case comes to the surface along anticlines of the strata, passes up conformably into the overlying Gala Group (belonging to the Upper Caradoc and Llandovery period) in several localities in the southern districts, but to the north the basement bed of the latter rests usually on the Lower Moffat beds, so that there appears to be in many cases an entire absence of Upper Llandeilo and Lower Caradoc Rocks in that direction; the Lower Llandeilo being succeeded immediately by the Upper Caradoc beds.

In 1876 appeared a series of papers of the highest value by Professor Lapworth "On Scottish Monograptidæ," published in the Geological Magazine.* These publications revealed an important advance in the author's views regarding the geological structure of the southern portion of the Silurian tableland. Discarding the great anticline between Berwick and Dumfries, he maintains that the Hawick Rocks (the axial beds) pass conformably upwards into the Upper Silurian strata (Riccarton and Kirkcudbright) and form the highest members of the Middle Silurian series overlying the Moffat Shales. Regarding the three divisions of the Moffat Shales, he states that the Lower is of Llandeilo age, the Middle represents a portion of the Bala formations of North Wales, and the Birkhill Group belongs, in part at least, to the epoch of the Lower Llandovery.

The author describes in detail the vertical range and distribution of the *Monograptidæ* in the Silurian rocks of the South of Scotland. From a review of all the facts he infers that we have sufficient evidence to justify us in accepting the following generalisations:—

(1) Of the numerous forms of graptolites belonging to the family of the *Monograptidæ* in the South of Scotland, each has a certain definite restriction in the vertical series of deposits.

(2) The three successive rock groups of Birkhill, Gala, and Riccarton each possess a well-marked assemblage of *Monograptidæ* which is easily separated as a whole from that of the other formations.

(3) The general vertical succession of species and varieties of the *Monograptidæ* in these rocks is in complete accordance with that in Ireland, Westmoreland, Central Europe, and Scandinavia.

In the same year Professor Lapworth contributed the chapter on "The Silurian System of the South of Scotland" to the

* Geol. Mag. Vol. III. (New Series), pp. 308, 350, 499, 544.

"Catalogue of the Western Scottish Fossils," prepared for the meeting of the British Association at Glasgow, in which he gives a Table showing the succession of the strata with their English equivalents. The Birkhill Shales, Gala Group, and Hawick Rocks are viewed as one formation—the Valentian—from the ancient Roman name of the South of Scotland—their English equivalents being the Llandovery, Mayhill, and Tarannon beds respectively.

Regarding the Leadhills district, the author states that there are no Birkhill Shales in this area (unless indeed they are represented by the lowest Valentian zones), the highest black shales visible being the top zones of the Middle Moffat or Hartfell Shales. The Lower Moffat Shales occur in most localities, and the peculiar indurated bands of siliceous flag are often remarkably conspicuous. Every fossil of the Lower Moffat Shales has already been collected from this area, and there seems to be a perfect similarity in their vertical range in the Leadhills and Moffat districts.

The Valentian Rocks of the Leadhills are almost identical in lithological character with those of the Moffat area. Sometimes they contain fossiliferous zones, as at Duntercleuch, Snar, Wallace's Cast, &c. On the same horizon, however, similar fossiliferous bands occur in Peeblesshire at Wrae Hill, Stobo, Kilbucho, and Winkstone, and to the south-west near Moniaive and Dalry. The fossils show that the beds are in all probability of Llandovery age and the continuation of the fossiliferous deposits of the Girvan area.

A provisional classification of the rocks in the Girvan district is likewise given, comprising (a) the crystalline and metamorphic rocks of Ballantrae, and (b) the fossiliferous limestones, the majority of the fossils being considered as of Bala age. These are followed by the representatives of the Lower Girvan Series and Upper Girvan Series. Lists of fossils are given, and many of the graptolites characteristic of the different groups are figured.

In 1878 appeared Professor Lapworth's memoir on "The Moffat Series" in the Quarterly Journal of the Geological Society.* The publication of this paper marks an epoch in the history of the Silurian Geology of the South of Scotland. It remains the greatest and most original contribution to the study of the life-sequence and structural relations of these highly convoluted rocks. For nearly ten years the author had devoted himself to the mapping of the various outcrops of the black shale series throughout the Southern Uplands. Selecting the Moffat district as a typical area where the sub-divisions of the series are admirably exposed, he unfolded in detail the structure of that interesting region. The paper is illustrated with maps and sections of the district extending from Annandale to St. Mary's Loch and from the Vale of Ettrick to Hartfell. Taking Dobb's Linn and Craigmichan Scaurs as typical

* Quart. Jour. Geol. Soc. Vol. XXXIV., p. 240 *et seq.*

sections showing the sequence and palæontological features of the Moffat series, he demonstrates the true order of succession of the strata based on the vertical range of the graptolites. He describes the prominent parallel bands to the north and south of the Moffat valley, and by means of confirmatory sections places his conclusions beyond all doubt. The various sub-divisions, lithological characters, and fossil zones are treated in great detail; a Table showing the vertical distribution of the fossils is given, and the respective faunas of the three divisions of the Moffat Series are compared with their foreign equivalents. The main conclusions are here briefly summarised:

1. The black shales of the Moffat region are portions of one band, repeated by parallel folds, the axial planes of which are usually inverted; the thickness in this district is 300 feet, but the base is not seen.
2. They fall into three groups: the Glenkiln, Hartfell, and Birkhill, corresponding to the Upper Llandeilo, Caradoc, and Lower Llandovery formations respectively. Each group is divisible into zones, characterised by special mineralogical and palæontological features.
3. Compared with the development of these formations in Wales, there is a marked north-westerly attenuation of the Lower Silurian rocks in Britain—a feature which is common to the Silurian rocks of Europe.
4. Passing from Moffatdale northwards to the north-west margin of the Southern Uplands, the black shale zones gradually disappear, till near the edge of the chain there is only a greatly degenerated representative of the Hartfell-Glenkiln division. To the south of the Moffat district the greywackes and shales rest on the Birkhill (Lower Llandovery) Shales in the Ettrick valley, and after innumerable foldings in Eskdalemuir they pass conformably upwards into the Riccarton beds (Wenlock).

Perhaps one of the most striking palæontological features of this paper is the great distinction between the graptolite faunas of the two lower divisions and that of the Birkhill Shales; indeed the boundary line marks a distinct palæontological break (see p. 57).

In 1879 appeared Professor Lapworth's monograph on "The Geological Distribution of the Rhabdophora," in which he gave a comprehensive view of the evidence bearing on the vertical distribution of the graptolites in the Lower Palæozoic rocks of Europe and America. This paper was accompanied by a valuable series of Tables showing the range of the graptolites in the different divisions of the Lower Palæozoic systems.*

In connection with this review of the geological literature bearing on the black shales and their organic remains, reference

* Annals and Mag. of Nat. Hist.. Ser. 5. Vol. III., pp. 245, 449.

ought to be made to the researches of Professor H. A. Nicholson, of Messrs. Carruthers, Hopkinson, W. Dairon, and others who have described and figured fossils from these bands.

Before proceeding to indicate the results of Professor Lapworth's detailed investigations in the Girvan district we must call attention to certain palæontological researches relating to the extensive series of fossils from the Silurian rocks of that region. It is noteworthy that considerable difference of opinion has arisen among geologists and palæontologists as to the age of the prolific fossil-bearing zones and associated strata of the older Palæozoic rocks of the Girvan area. In many instances this is doubtless due, as Professor Lapworth truly states, to the fact that the larger proportion of fossils has been obtained from a few limited areas, and mainly from half a dozen different horizons, while the less fossiliferous strata have been left practically untouched. In some cases, however, as will be shown in the sequel, it may be accounted for by the conflicting nature of the evidence supplied by different groups of organisms from one and the same band. In the Appendix to this volume dealing with the Bibliography, upwards of twenty palæontological memoirs referring to the Silurian rocks of Girvan are enumerated; at present we shall refer only to those bearing on the order of succession.

In the volume on "British Palæozoic Rocks and Fossils," published in 1855, by Sedgwick and M'Coy, many of the types from the Girvan region are figured and described, and horizons are assigned to some of the fossil-bearing zones. The Craighead Limestone is referred to Upper Bala time, the Aldons Limestone to the Lower Bala, and the Mulloch Hill Sandstones and Drummuck beds to the Upper Bala formation.

In the "Catalogue of Cambrian and Silurian Fossils" in the Cambridge Museum, prepared by Mr. Salter, with a preface by Sedgwick, which appeared in 1873, the Stinchar Limestone (including the limestone visible at Aldons, Bougang, and Knockdolian) is assigned to the Lower Bala horizon (Llandeilo); the Craighead Limestone, with the Glenwhapple and Ardwell beds, to the Middle Bala position; while the Drummuck and Mulloch Hill beds are relegated to the Upper Bala formation.*

In Mr. Salter's unfinished Monograph of the British Trilobites (1864-83), only a few of the types of this group from the Silurian rocks of Girvan are figured and described; but viewing these species in the light of the known vertical range of the trilobites in the Lower Palæozoic rocks of Wales, he groups the Craighead Limestone and Penwhapple beds with the Caradoc formation (Murchison), and the Drummuck Mudstones and Mulloch Hill Sandstones with the Llandovery Rocks. From the Bougang Limestone (the representative of the

* In the classification of the Lower Palæozoic rocks given in this volume, the terminology here used is clearly defined; the Lower Bala group (Sedgwick) represents the Upper and Lower Llandeilo rocks (Murchison); the Middle Bala group (Sedgwick). the Caradoc and Bala rocks (Murchison); and the Upper Bala group (Sedgwick) is the equivalent of the Lower Llandovery formation of Murchison.

Stinchar Limestone) Salter records the tail of a trilobite which he doubtfully refers to *Asaphus (Isotelus)*, assigning it to the horizon of the Llandeilo flags.

In the Monograph of the Silurian Brachiopoda (1864-1871) by Mr. Davidson, various forms from the Girvan region appear, and are referred to certain definite horizons. An analysis of these references shows that the Craighead Limestone, Balclatchie and Ardwell beds are assigned to the Caradoc formation, while the Saugh Hill grits, the Penkill beds, and Mulloch Hill Sandstones are grouped with the Llandovery Rocks. The Supplement to the foregoing Monograph (1882-4) contains a special section devoted to Scottish Silurian Brachiopoda, in which the author has followed the stratigraphical sub-divisions for Ayrshire propounded by Professor Lapworth and the list of localities furnished by Mrs. Gray. In his general list, the Craighead Limestone is now referred to the Llandeilo instead of the Caradoc formation, the beds at Balclatchie, Dow Hill, and Ardmillan Brae are classed as Llandeilo; the strata at Whitehouse Bay and Shalloch Mill are regarded as Middle Caradoc, and the Trilobite Mudstones of Drummuck as Upper Caradoc.

In the three Fasciculi of the valuable Monograph of the Silurian Fossils of the Girvan District by Professor H. A. Nicholson and Mr. R. Etheridge, jun. (1878-80), a systematic descriptive account is given of a large series of organic remains from that region, numerous types are figured, and suggestions are made regarding the probable age of some of the fossil-bearing zones. From an examination of the corals, Professor Nicholson arrived at the following conclusions:

1. The Craighead Limestone is of Lower Silurian age, corresponding perhaps with the upper part of the Trenton Limestone, or the beds of the Cincinnati and Hudson River formations of North America.
2. The Mulloch Hill beds represent the Upper Llandovery or May Hill Sandstone of "Siluria."
3. The Penkill beds near Girvan (greenish-grey mudstones in Penwhapple Glen) must find their place towards the lower portion of the Upper Silurian series.
4. The Shalloch Mill beds with a thin band of coralline limestone are referred to Upper Silurian time.
5. The Balclatchie beds, described as dark green coarse-grained volcanic ashes (Balclatchie grits), are probably low down in the Silurian series.

On the other hand, from the evidence supplied mainly by the trilobites, Mr. Etheridge, jun., thus summarised the results of his investigations:

1. The Craighead Limestone and Shale may be of Caradoc age.
2. The Mulloch Hill beds are referable to the Lower or Upper Llandovery formation.

3. The Penkill beds contain a peculiar mingling of species of trilobites, the majority indicating the lower part of the Upper Silurian system.

4. The trilobites of the Balclatchie mudstones and grits have a strong Caradoc facies, though a few forms are equally typical of other horizons.

5. The trilobites from Ardmillan Brae are mainly Caradoc.

6. The matrix at Penwhapple more or less resembles that at Balclatchie, and the beds are probably Caradoc.

7. The Drummuck mudstones will probably turn out to be of Lower or Upper Llandovery age from the evidence afforded by the trilobites—a suggestion which will be dominated by the mollusca found in association with them.

8. The beds in Thrave Glen are probably of Llandovery age.

9. The Aldons Limestone, in accordance with Professor M'Coy's conclusion, is assigned to Lower Bala time (Llandeilo).

The statements made in the foregoing paragraphs will be sufficient to show the divergence of opinion among palæontologists regarding the age of some of the prolific fossil-bearing zones in the Girvan region; but though no reliable order of succession had been established, the various investigators were agreed that there are representatives of Llandeilo, Caradoc, and Llandovery strata in the Lower Palæozoic rocks of Girvan.

In connection with the development of palæontological research among the Silurian fossils of Girvan, special reference ought to be made to the magnificent collection of organic remains from the Silurian rocks of that region, made by Mrs. Robert Gray and various members of her family. This unique collection, numbering about 30,000 specimens, was placed at the service of Professor H. A. Nicholson, Mr. Etheridge, jun., Professor Lapworth, and others to aid them in their investigations; indeed, the authors of the Monograph of the Silurian Fossils of Girvan frankly acknowledge their great debt of gratitude to Mrs. Gray, without whose co-operation that work could not have appeared. In the preparation of the Palæontological Appendix to the present volume, Mrs. Gray has rendered great service by drawing out a list of organic remains from the Lower Palæozoic rocks of Girvan; the various localities being furnished by herself, and the stratigraphical grouping being based on the order of succession established by Professor Lapworth.

An important contribution was made by Professor Bonney in 1878 to the study of the crystalline rocks of Ballantrae, in which he demonstrated the truly igneous character of the serpentine, gabbro, porphyrites, &c., of that region.* From a consideration of the field evidence and the results of microscopic examination he arrived at the following conclusions:

1. That the serpentine of this district is intrusive and, like so many others, is an altered olivine rock.

* "On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast." Quart. Jour. Geol. Soc. Vol. XXXIV. p. 769.

2. That there is no hypersthene rock, but gabbros of two ages, both of igneous origin, the first extraordinarily rich in diallage, so that it can hardly be called a gabbro, the second much resembling the later gabbro of the Lizard, Cornwall.

3. That the porphyrites of Balcreuchan and Pinbain Hill are true igneous rocks, and very probably remnants of lava-flows associated with tuffs or agglomerates.

4. That several of the rocks into which the serpentine is intrusive are also igneous, and are augitic, not hornblendic.

5. That there are some doleritic and basaltic dykes of later date than all the above.

Regarding the age of the rocks, he suggested that the last-named basalts are probably Miocene, that the porphyrites are probably outliers of Middle Old Red Sandstone age, and that the serpentine is intrusive in the Lower Silurian rocks of the region, and therefore of later date.

In 1882, Professor Lapworth communicated the results of his detailed mapping of the Girvan area to the Geological Society of London. Having established the vertical range of the graptolites in the Moffat Shales, and having defined the stratigraphical equivalents of their main divisions in Wales and other regions, he approached the study of the stratigraphy of the Girvan rocks from a fresh standpoint. The following is a summary of his main conclusions regarding the order of succession:

1. Selecting the Benan Hill conglomerate as the primary horizon of reference, he shows that it is merely the central member of a series (the Barr series) of boulder beds and conglomerates, with intercalary zones of limestone and fossiliferous shales. It includes the Craighead or Stinchar Limestone as a subordinate member near its base, where it is divided from the underlying Ballantrae Rocks by a calcareous conglomerate and breccia of irregular thickness.

2. The Barr Series is overlain by the Ardmillan Series, composed throughout of graptolite flagstones and shales, which nevertheless arrange themselves naturally in several distinct sub-formations. The higher and lower divisions (the Ardwell, Barren Flagstone and Drummuck beds) have their respective positions fixed by stratigraphical evidence. The proper relations of its central divisions (the Cascade and Whitehouse beds), the strata of which are usually inverted, are established mainly by geographical considerations.

3. The graptolite series of Ardmillan is followed by the Newlands Series, consisting of Brachiopod-sandstones, *Pentamerus* grits, and *Monograptus* shales. The position of the first sub-division of the series (Mulloch Hill beds) is fixed by its relation to the terminal beds of the older Ardmillan series, and the place of the highest division (the Camregan group) by its relation to the newer Dailly series. The position of the central division (the Saugh Hill group) is deduced with equal certainty

from its intermediate place in the series. The sequence, however, of the component strata of this central division is rendered so dubious, by inversion, faulting, and local unconformities, that only a provisional classification of its minor zones is possible.

4. The Dailly Series forms the fifth division, being at once the thickest and most homogeneous series in the Girvan succession, comprising the Penkill, Bargany, and Straiton beds.

One of the remarkable features of Professor Lapworth's investigations in the Girvan area is his identification there of certain graptolite zones which are characteristic of the Moffat Shales and overlying Bala group. For example, in the shales associated with the Stinchar Limestone series, he records the presence of *Didymograptus superstes*, *Dicellograptus sextans*, &c., which are typical of the Glenkiln division (Moffat); in the Ardmillan series he finds *Climacograptus caudatus*, *Dicellograptus Forchhammeri*, *Leptograptus flaccidus*, *Pleurograptus linearis*, *Diplograptus truncatus*, &c., indicating Hartfell horizons: in the Newlands series he chronicles *Diplograptus modestus*, *Monograptus Sedgwicki*, and *Rastrites maximus*, &c., some of which are zonal forms of the Birkhill division; in the Dailly series he notes *Crossopodia*, *Protovirgularia*, *Monograptus exiguus*, *Monograptus galaensis*, *Cyrtograptus Grayi*, *Monograptus priodon*, *M. vomerinus*, &c., occurring partly in the Gala group and partly in the Wenlock beds. The discovery of these graptolite zones in the Girvan area threw a flood of light on the stratigraphical horizons of that complicated region. He was thus enabled to demonstrate that Murchison had been misled by the apparent synclinal arrangement of the strata on the plateau on the south side of the Girvan valley, and that he had thus erred in placing the *Pentamerus* grits of Saugh Hill on a lower horizon than the graptolitic flagstones of Ardwell and Penwhapple Glen (Ardmillan series). Over much of that region the beds are inverted, and hence no reliable conclusions can be based on mere superposition.

In his paper on "The Girvan Succession" Professor Lapworth further states that the Girvan rocks appear to repose, at their base, on the generally older igneous and altered rocks of Ballantrae, but they had been too imperfectly studied to hazard any conclusion regarding their age. He made the important announcement, however, that fragments of Ballantrae igneous rocks occur in the Kirkland or purple conglomerate at the base of the Girvan sequence, and hence many of the Ballantrae volcanic rocks must be older than the basement beds of the Girvan succession. He suggests that these pre-Girvan lavas and ashes must either represent the Arenig and Llandeilo volcanic rocks of Wales and Cumberland, or must be of more ancient date. On the other hand, rocks which are unquestionably of true Girvan age occur at many localities within the typical Ballantrae region itself, while the patches of altered or so-called

Ballantrae rocks found outside that area almost certainly include some greatly altered Girvan rocks.

In addition to the unconformability at the base of the Girvan succession, Professor Lapworth showed that the sequence of the Girvan rocks is broken by one fairly distinct unconformability, viz., that at the base of the Craigskelly conglomerate. He adds that the presence of boulder beds at the base of the Mulloch group, at the base of the Saugh Hill grits, and elsewhere, renders it probable that other local breaks may be detected.

In the January number of the Geological Magazine, 1889, there appeared Professor Lapworth's final contribution to the stratigraphy and palæontology of the Silurian rocks of the Southern Uplands.* In Part I. of this communication Professor Lapworth states that the Ballantrae rocks have been regarded by him as a complex formed of : (a) the Stinchar Limestone and conglomerate series, (b) a stratiform series of sedimentary and volcanic rocks of much earlier date, (c) intruded igneous masses of subsequent but unknown geological age. In order to study the Ballantrae rocks in greater detail, and to establish on palæontological grounds the pre-Girvan age of these members of the Ballantrae complex which were held by him to be of higher antiquity than the basement beds (Upper Llandeilo) of the Girvan succession, he paid a visit to this district in 1885, when he obtained evidence which led him to the following conclusions:

1. The diabases, syenites, gabbros, and serpentines occurring in the altered patches within the limits of the Girvan district are mostly, if not all, of post-Girvan age. They occasionally traverse, harden, and alter such of the Lower Girvan rocks as they are locally associated with, and they have intruded themselves mainly in sheets along the many anticlinal arches into which the Girvan rocks are thrown, either between the Girvan rocks and the Ballantrae rocks proper, or among the limestones and conglomerates which make up the basal members of the Girvan succession.

2. The Ballantrae rock-complex further includes contemporaneous volcanic and sedimentary rocks, some of the last of which are distinctly of pre-Girvan date, for they contain locally a well-marked graptolitic fauna of middle Arenig age, occurring in black shales on the sea-shore at Bennane Head. A list of the fossils is given, together with a Table showing their distribution. Professor Lapworth further states that the Ballantrae series forms a complex of stratified, altered, and igneous rocks of very different geological ages (Arenig, Llandeilo, and Post-Ordovician), the common facies of the pseudo-series being mainly the result of the common interfolding, alteration, and intrusion which its rocks have undergone.

In Part II. of this communication he indicates the distribution and physical relations of the various rock formations entering into the structure of the Southern Uplands.

Disregarding the lowest strata (the Ballantrae or Arenig rocks), which are supposed to come to the surface only within the limits of the Ballantrae district, and the highest strata (Wenlock-Ludlow), which merely skirt the upland plateau on its north-west and south-east flanks, Professor Lapworth arranges almost the whole of the Lower Palæozoic strata of the uplands in two grand lithological divisions.

1. A lower Terrane (Moffat Terrane), including strata ranging from the Upper Llandeilo to the Upper Llandovery.
2. An upper Terrane (Gala or Queensberry Terrane), embracing strata generally of Tarannon age.

The rocks of the Lower or Moffat Terrane attain their maximum development in the Ballantrae-Girvan district, where they include (a) the Barr or Stinchar series (Bala-Llandeilo), (b) the Ardmillan series (Bala-Caradoc), and (c) the Newlands series (Llandovery). These groups are composed of strata of variable lithological characters, containing an abundant fauna of the usual Lower Palæozoic life types, with an aggregate thickness of about 4000 feet. Followed across the uplands towards the south-east, they rapidly diminish in thickness as they reappear in various anticlines, till in the Moffat district they are reduced to 300 or 400 feet in thickness. Here the Moffat Terrane, consisting mainly of black, grey, and white shales, is represented by (a) Glenkiln shales, (b) Hartfell shales, (c) Birkhill shales, charged with a fauna almost exclusively graptolitic.

The members of the overlying Gala or Queensberry Terrane are represented in the Girvan district by the Dailly series, upwards of 2500 feet thick, consisting mainly of repetitions of grey grits, flagstones, and red and purple shales. The strata grow thicker and coarser as they are followed eastwards across the uplands, but in the central parts of the plateau a lower (Queensberry) and a higher (Grieston) division can still be roughly made out. Still further to the south-east the beds become finer in grain and decrease in thickness till they plunge underneath the Wenlock Rocks of Riccarton and Kirkcudbright. After stating that the main mass of the visible rocky floor of the Southern Uplands is formed of members of the Gala Terrane, Professor Lapworth proceeds to indicate that the pseudo-synclinal arrangement of the strata in the Leadhills area is an example of the "fan structure" of mountain areas (endocline) where we may naturally expect to find the deepest strata, and that the pseudo-anticline of the Hawick line is due to inverted "fan structure" (exocline) where the highest strata may occur.

The exposures of pre-Gala strata are disposed in broad geographical bands or zones, ranging north-east and south-west, of which the following three are specially conspicuous: (1) the south-east band of Wigtown, Moffat, and Melrose, (2) the central band of Portpatrick, Leadhills, and Lammermuirs, (3)

the western zones of Ballantrae and Girvan. In the Moffat-Melrose anticlines the members of the Moffat series appear as narrow "inliers" among the Gala rocks, while in the anticlines of the Leadhills-Moorfoot band the exposures are often more than a mile across. In the latter region the strata of the locally thick Moffat series are occasionally laid bare to a depth of at least 2000 feet down to the calcareous strata at their base (Duntercleuch and Wrae). In the Girvan region the locally massive Moffat series forms a belt four or five miles across; the beds are exposed from base to summit, and the underlying Arenig rocks are laid bare.

In working out the order of succession throughout the uplands, Professor Lapworth states that graptolites must play the chief part, as they are almost the only fossils met with in the strata of this wide region. The known restriction of the entire family of the *Monograptidæ* to Silurian strata (Upper Silurian, Murchison and the Geological Survey) affords the means of determining the outcrop of the upland boundary between the Ordovician (Lower Silurian, Murchison and the Survey) and the Silurian (Upper Silurian) rocks. He suggests that the outcrop of the main boundary line between the strata of these two systems will be found to pass obliquely across the tableland from near Dunbar, by the south of the Moorfoots, the valley of the Tweed, near the Crook, to the sea-coast south of Portpatrick. North of this line, the mass of the strata will be found to be Ordovician (Lower Silurian); such (Upper) Silurian rocks as occur forming outliers parallel with the great boundary fault. South-east of this line, the mass of the strata must be classed as Silurian (Upper Silurian); the Ordovician (Lower Silurian) rocks occurring only locally as long lenticular inliers, gradually diminishing in systematic importance as they are followed across the country from north to south and from east to west.

Professor Lapworth gives various sketch sections across the uplands, illustrative of his views of the general disposition and inter-relationships of the strata, together with a "Table of Correlation," showing the more important palæontological data which bear on the question of the upland sequence.

In the spring of 1888 the re-examination of the Southern Uplands was begun by the Geological Survey. Messrs. Peach and Horne, accompanied by Mr. Macconochie, mapped the sections at Ettrickbridge-end, in the Tima Water, and south-west to Wamphray; and, in the northern part of the tableland, the tract between Abington and the Culter Water, south to the valley of the Tweed. An official report embodying the results of their work was forwarded in the same year to the Director-General, in which they finally abandoned the order of succession hitherto followed by the Survey. The following points, among others, were given in this report:

1. In the course of the survey of the Abington area they discovered a series of volcanic rocks (diabase lavas and

agglomerates) associated with a prominent zone of cherts and the Glenkiln black shales charged with typical graptolites of that division. In the field, Mr. Peach observed numerous minute organisms in the cherts, which were subsequently determined to be radiolarians by Professor H. A. Nicholson and Dr. Hinde. The volcanic rocks come to the surface along anticlinal folds, and occupy a lower horizon than any beds in the Moffat area; being in all likelihood of the same age as the contemporaneous lavas and tuffs at Ballantrae, Ayrshire.

2. The fossiliferous grits and conglomerates (Duntercleuch, Glendowran, &c.) are associated with the Glenkiln-Hartfell black shales, and are apparently of Caradoc age; the Lowther shales with the lenticular bands and nodules of limestone (Wrae Limestone) are probably the equivalents of the Barren Mudstones of the Moffat series (Upper Hartfell), and therefore of Caradoc age.

3. The northern outcrop of the base of the Llandovery Rocks (Queensberry Grits and Dalveen Group) is indicated by flaggy shales with bands of dark or black shales yielding dwarfed forms of graptolites, probably representing the basal beds of the Birkhill division.

4. In such a highly contorted region as that of Abington, the apparent order of superposition is entirely misleading, and the only method of determining the succession is by means of the graptolite zones established by Professor Lapworth in the Moffat region.

In 1890, Dr. Hinde published the results of his examination of the collection of cherts obtained by the Geological Survey from the Abington area, which was submitted to him for determination.* He concludes that this "chert may be fairly considered to be due to the accumulation of the tests of radiolaria, and is thus a pure radiolarian rock equally as much as the Tertiary beds of Barbadoes and Nicobar Islands, which, according to Haeckel, correspond to the recent radiolarian ooze and are of deep-sea origin, having probably been deposited at depths greater than 2000 fathoms. If the same conclusion is applicable to this fossil chert, it may represent, as Professor H. A. Nicholson† has already pointed out, a true deep-sea deposit in the Palæozoic period, the existence of which in the geological series has of late been disputed. The beds of fine-grained red and green mudstones associated with this chert likewise favour the same view of its origin in deep water."

In 1889,‡ a paper was contributed to the Royal Society of London by Mr. Allport and Professor Bonney, on the contact metamorphism of the Silurian rocks by the granite west of New Galloway. In 1890,§ another important communication

* Annals and Magazine of Nat. Hist., July 1890, p. 45 *et seq.*

† Trans. Edin. Geol. Soc. Vol. VI., Part I., p. 56.

‡ Report on the effects of Contact-Metamorphism exhibited by the Silurian rocks near the town of New Galloway. Proc. Roy. Soc., London. Vol. XLIX. (1889), p. 79.

§ Contact alteration near New Galloway. Quart. Jour. Geol. Soc. Vol. XLVI. (1890), p. 569.

was made by Miss Gardiner to the Geological Society of London, in which she described the alteration of Silurian sediments into sillimanite-gneiss in contact with the New Galloway granite. These papers are more specially referred to in the chapter dealing with contact metamorphism.

Since 1888, the re-examination of the Southern Uplands, in the light of Professor Lapworth's researches, has been carried on at intervals by the Geological Survey as the exigencies of the work in the Highlands permitted. In the Central Belt, between St. Abbs Head and the Mull of Galloway, all the known exposures of the Moffat series were re-examined, their structural relations ascertained, and fossils were collected sufficient to determine the horizons of the main divisions of that series. The important structural line marking the northern limit of the Llandovery and Tarannon rocks of the Central Belt has been traced across the uplands from the slopes of the Lammermuir Hills to the western headlands of Wigtownshire—a labour attended with considerable difficulty, owing to the gradual disappearance of the Birkhill shales with most of their fossils and their replacement by coarser sediments. In the Northern Belt, from the Lammermuir Hills to Loch Ryan and Portpatrick, all the known exposures of the Moffat shales were likewise re-mapped, the respective boundaries of the Arenig volcanic rocks and overlying radiolarian cherts were traced, and fossils were gathered to fix the horizons of the succeeding Glenkiln-Hartfell shales. Again, in the Girvan area, the volcanic and plutonic rocks of Ballantrae were re-mapped, and their relations to the Arenig igneous rocks and radiolarian cherts of the uplands were ascertained, while the main sections of the Girvan succession, mapped and described by Professor Lapworth, were re-visited. During the prosecution of the re-survey portions of the large granite masses and of the aureoles of contact metamorphism were re-examined, and materials were obtained for petrographical description. Finally, the Upper Silurian inliers of Lanarkshire and the Pentland Hills were re-traversed, the sub-divisions of the Downtonian rocks in these areas were ascertained, and their fossiliferous zones successfully traced. Sheets 16 and 8 of the one-inch map of Scotland have been published in the course of the re-survey, and a revised edition of Sheet 7 has just appeared.

The results of the re-examination of the Southern Uplands by the Geological Survey have, from time to time, been summarised in the Annual Reports of the Director-General, and may be briefly recapitulated as follows:

1. The occurrence of a series of Arenig volcanic and plutonic rocks on various anticlines over an area of about 1500 square miles.

2. The existence of a well-marked band of radiolarian cherts and mudstones, overlying the foregoing volcanic series, which has been traced over a part of the uplands measuring about 2000 square miles.

3. The main band of radiolarian chert and mudstone, though about 70 feet thick, represents the succession of deposits which, elsewhere in Britain, intervene between the Middle Arenig and uppermost Llandeilo strata.

4. The occurrence at various localities over a limited area of volcanic rocks of Llandeilo and Caradoc age.

5. During the examination of the various black shale outcrops throughout the uplands, a great amount of detailed evidence has been obtained, confirming the order of succession established by Professor Lapworth, and the lateral variation of the strata between Moffat and Girvan.

6. The inclusion of the Downtonian strata of Lanarkshire and the Pentland Hills in the Silurian system, owing to the discovery of fishes, eurypterids, &c., resembling those occurring in the Ludlow rocks of Lanarkshire and other regions.

Summary. In the foregoing pages we have endeavoured to give a historical account of the development of research in the Silurian rocks of the Southern Uplands, from which it will be seen that considerable detail has been introduced in order that justice might be done to the various investigators. Before concluding this sketch it is desirable to place clearly on record the distinctive features of Professor Lapworth's achievements, both palæontological and stratigraphical, which resulted in establishing the true order of succession of the strata.

1. From the outset he clearly recognised that a detailed study of the vertical distribution of the graptolites might furnish the key to the true interpretation of the structure of the region.

2. While collecting the fossils, zone by zone, in the Moffat region, he found that certain forms occur as distinct and consecutive faunas, which always preserve the same relative sequence though the strata may be inverted by folding.

3. When tracing the black shale bands throughout the uplands, he proved, by means of the successive graptolite faunas, a remarkable variation in the character of the contemporaneous sedimentary deposits; the black shales of the Central Belt (the Moffat series), which do not exceed 300 feet in thickness, being represented in the Girvan area by several thousand feet of sediments.

4. By his researches on the geological distribution of the Rhabdophora he showed that the sequence of graptolite faunas established in the Southern Uplands likewise extends over Europe and North America.

5. The determination of this faunal sequence disposed of the order of succession of the Silurian rocks of the South of Scotland based on Barrande's doctrine of Colonies, corrected erroneous estimates of the thickness of the strata, and enabled the structure of the uplands to be worked out in the most highly complicated districts.

CHAPTER III.

General Description of the Silurian Rocks of the Southern Uplands of Scotland. I. Stratigraphy. II. Tectonic Arrangement.

In this chapter we propose to give a brief sketch of the geological history of the Silurian strata of the Southern Uplands, describing, first, the characters of the rocks and fossils in chronological order, and indicating the probable physical conditions which prevailed during each successive period; and second, the present tectonic arrangement of the strata as produced by the main elevation of the tableland at the close of Silurian time, and modified by subsequent denudation.

I. STRATIGRAPHY.

At the outset it is necessary to state clearly that, with the exception of certain areas where local unconformabilities prevail, the Silurian strata of the Southern Uplands point to continuous sedimentation from Arenig to Ludlow and Downtonian time; and further that, in the case of many of the great divisions of the system, there is a constant change in the nature of the sedimentation, as we pass from the Central Moffat region northwards and westwards by the Leadhills to the Girvan area. It is therefore essential to trace each successive rock-group, from the Moffat area towards the northern margin of the tableland, in order to understand the variation in the character of the strata, and the consequent changes in the nature of the fauna resulting from the altered physical conditions to which these variations point.

For the sake of convenience of description, the Silurian tableland has been divided into the following geographical belts, based on the geological relations of the strata (see Map):

1. The Southern Belt, comprising the Wenlock and Ludlow Rocks along the southern margin of the tableland.
2. The Central Belt, from twenty to twenty-five miles in width, composed mainly of Llandovery and Tarannon Rocks (b^4), stretches from the Mull of Galloway north-eastwards by Castle-Douglas and Moffat to Melrose and thence to St. Abbs Head.
3. The Northern Belt, occupied by Arenig, Llandeilo, and Caradoc Rocks (b^1, b^2, b^3), extends from the northern slope of the Lammermuir Hills south-westwards, through the Moorfoot and Leadhills by Sanquhar to Loch Ryan and Portpatrick.
4. The Girvan area, comprising the districts in the neighbourhood of Girvan, Ballantrae, Blair and Straiton.

LOWER SILURIAN.

ARENIG.

CENTRAL BELT.

Rocks.—The strata consist of cherts, mudstones, and grey shales, which at certain localities are associated with fine volcanic tuff.

Fossils.—The cherts are charged with radiolaria which, in this belt, have not been named; the best specimens for determination being obtained from the Northern Belt.

Conditions of Deposition.—The deposits imply the prevalence of oceanic conditions throughout the central area, with clear water, beyond the limit of sedimentation, save in some exceptional instances where fine terrigenous material was mingled with the radiolarian ooze. The fine tuffs likewise indicate volcanic activity, or at least the diffusion of volcanic material over the floor of the ocean in this portion of the Silurian region during the Arenig period.

NORTHERN BELT.

Rocks.—The lowest visible strata are of volcanic origin, comprising lavas of various types (diabase, "diabase-porphyrite," and mica-andesite), together with agglomerates and tuffs, of which perhaps the most interesting is the augite-andesite tuff of Bail Hill, Sanquhar. These are traversed by intrusive igneous materials, including dolerites and gabbros.

Overlying the volcanic series comes an important development of cherts and mudstones, which, where typically developed in the Abington area, may be grouped in three sub-zones. The lowest of these is composed of red or chocolate-coloured cherts embedded in a fine ashy matrix, possibly of volcanic origin, which, when the matrix is exposed to weathering, bleaches to a white colour. The middle and upper sub-zones consist of green and grey cherts respectively, which occur as elongated flattened nodules from a few inches to a few feet across. Frequently they coalesce so as to form a more or less persistent bed. These banded cherts, the upper surfaces of which are often mammillated or botryoidal, vary in thickness from a few inches to a foot or more, and give rise to a remarkable ribbed contour which is a characteristic feature of the series. They are associated with green, grey, and red mudstones, sometimes several inches thick, which by the admixture of siliceous material pass laterally into chert. In one or two sections a thin seam or film of black shale is intercalated between the overlying mudstones and cherts and the underlying volcanic rocks.

Fossils.—The cherts are abundantly charged with radiolaria. From the researches of Dr. Hinde, in whose hands the collection of cherts made by the Geological Survey was placed for examination, it appears that, in thin sections of the unstained rock, the organic remains, when viewed under the microscope,

look like larger and smaller circles filled with somewhat lighter material than the surrounding matrix. In this condition no structure is observed. In sections of the red or jaspery chert, the outlines of the radiolaria are more clearly defined, the radiating spines being sometimes seen. In the unstained and red cherts, the radiolaria are only represented by casts, their tests having been dissolved or otherwise rendered indistinguishable. Where, however, the rock has been stained by a dark or black substance, due to carbon, iron, or manganese, the tests have been preserved in the material which has replaced the original silica. In these stained portions fairly perfect specimens of radiolaria have been found by Dr. Hinde, showing one or more concentric spheres and spines projecting from their surfaces.

From the collection of cherts Dr. Hinde has identified twenty-three new species of radiolaria, belonging to twelve genera, of which half are new, together with some spicules of hexactinellid sponges, and some minute toothed plates and detached denticles resembling the radulæ of naked molluscs. He infers, as already stated, that the chert is due to the accumulation of the tests of radiolaria, and is thus a pure radiolarian rock, like the Tertiary beds of Barbadoes and the Nicobar Islands.

The thin seam of black shale overlying the Arenig lavas in the Abington district has yielded specimens of the following Arenig graptolites: *Tetragraptus fruticosus*, *T. quadribrachiatus*, together with a phyllopod crustacean, *Caryocaris Wrighti* (p. 286).

The mudstones, immediately overlying the foregoing Arenig black shale, contain a profusion of hingeless brachiopods, similar to those which usually occur in graptolitic deposits, and belonging to the genera, *Acrothele*, 2 species; *Acrotreta*, 2; *Kutorgina*, 2; *Lingula*, 1; *Lingulella*, 3; *Linnarssonia*, 2; *Obolella*, 3; together with a glass-rope sponge (*Hyalostelia*) and Annelid jaws, referred to the genus *Arabellites*.

Conditions of Deposition.—The lavas, tuffs, and agglomerates prove that volcanic action was in full vigour in the northern area during the Arenig period, and in one instance, at Bail Hill, near Sanquhar, the augite-andesite agglomerate and tuff, which is there developed locally, seems to point to discharge from an adjacent centre. After the cessation of general volcanic activity, the waters remained clear, and allowed the accumulation of the radiolarian ooze. The shelly mudstones and thin graptolitic shale no doubt suggest nearer proximity of land than is indicated by the cherts, but when viewed in connection with their fossil contents, they clearly indicate an oceanic phase of sedimentation.

GIRVAN AREA.

Rocks.—Within the limits of the Girvan and Ballantrae region occurs the largest development of Arenig volcanic rocks in the Southern Uplands. They consist of a succession of

diabase and "diabase-porphyrite" lavas with interbedded tuffs and agglomerates, the diabase-lavas being fine-grained and vesicular, while the diabase-porphyrites contain large phenocrysts of felspar. One of the most striking and characteristic features of the lavas is the pillow-shaped or sack-like structure which they present in the field (Plate I.), the spaces between the spheroidal masses being sometimes filled with fine sediment such as black shale or limestone (Plate II.) From the distinctive petrographical types of the breccias and agglomerates near the top of the volcanic series, as, for example, the augite-andesite tuff of Mainshill, Ballantrae, and the diabase breccia of the conical hill, Knockdolian, it is clear that these pyroclastic materials must have been erupted from several independent vents.

The horizon of this succession of lavas and tuffs is clearly defined by the presence of fossiliferous flinty mudstones interleaved in the volcanic series, and by black graptolitic shales near the top, both of which yield graptolites of Middle Arenig age. Nowhere is the base of this volcanic series exposed within the limits of the Ballantrae and Girvan area, so that no estimate can be made of its total thickness, nor is it possible to fix the geological horizon of the earliest eruptions. Sir Archibald Geikie has, however, suggested that "possibly its visible portions represent merely the closing scenes of a long volcanic history which, over the area of the South of Scotland, extended into Cambrian time, like the contemporary series of Cader Idris."*

This volcanic series passes upwards into red, green, and grey cherts which are interstratified with tuffs and breccias that clearly overlie the Middle Arenig band of black shales. Indeed, the cliff sections leave no room for doubt that the radiolarian cherts were deposited contemporaneously with the volcanic eruptions, for not only are they intercalated with the breccias, but the latter likewise contain fragments of organic chert with radiolaria, which must have solidified on the sea-floor before its disruption by the explosions.

The interbedded lavas, tuffs, and agglomerates are associated with intrusive igneous materials of various petrographical types, comprising serpentine, olivine-enstatite rock, and gabbros, &c. At certain localities foliated gabbro, garnetiferous hornblende-schist, and chlorite schist appear among the intrusive masses, together with certain remarkable granulitic rocks which frequently show a banded structure. These basic masses have been subsequently invaded by dykes and lenticular bosses of dolerite which present chilled margins along their lines of contact with the surrounding rocks.

Fossils.—The organic remains found in the various sediments associated with the volcanic series underlying the radiolarian cherts consist mainly of graptolites of Middle Arenig facies; the following genera being represented: *Tetragraptus*, 6 species;

* "Ancient Volcanoes of Great Britain." Vol. I., p. 196.

Limestone filling spaces between pillow-form masses of lava exposed on beach near Downan, 1½ miles south of Ballantrae.

Dichograptus, 4; *Didymograptus*, 4; *Trigonograptus*, 1; *Phyllograptus*, 1; *Dendrograptus*, 1; *Climacograptus*, 1; and *Dictyonema*, 1. The phyllopod crustacean *Caryocaris Wrighti* is likewise recorded from these horizons. The genera of hingeless brachiopods hitherto met with in these sediments are not so numerous as those in the shelly mudstones of the same age in the Northern Belt, viz.: *Acrotreta*, 2 species; *Discina*, 1; *Lingula*, 1; *Obolella*, 2. Sponges are represented merely by their mooring rods (Plate XXVI.)

Though radiolaria have not been specifically described from the Girvan area, they occur in profusion in the various bands of chert, as may be readily seen by an ordinary lens.

Conditions of Deposition.—The succession of lavas and tuffs points to submarine volcanic eruptions which have been continued for a considerable lapse of time, the spheroidal masses of lava being surrounded by fine sediment transported from the existing land surface. During pauses in the eruptions fine sand and mud were accumulated on the sea-floor, in which were entombed the remains of hydrozoa, phyllopod crustaceans, and brachiopods. It is probable that as the volcanic episode advanced the sea-floor was slowly subsiding, for the land-born sediment disappears near the top of the series, and is replaced by radiolarian ooze, which must have been laid down in clear water. That the volcanic agencies had not become quiescent, however, but continued at intervals to break out anew, is proved by the fragments of lava and pieces of the already consolidated chert, which were evidently derived from the disruption of the sea-floor, and were buried in a fresh accumulation of radiolarian ooze.

LLANDEILO.

CENTRAL BELT.

Rocks.—The lower division of the Llandeilo Rocks throughout this region is represented by radiolarian cherts and mudstones which immediately overlie the Arenig band just described.

The upper division (Glenkiln Shales) is composed partly of black shales alternating with thin black cherts or flinty ribs, from one to three or four inches thick, and partly of grey and orange-coloured ashy mudstones, with bands of grey radiolarian chert, the latter being indistinguishable in hand-specimens from the chert which immediately overlies the Arenig volcanic rocks. These cherts are succeeded by a few feet of black shales, passing upwards into the overlying Hartfell black shales.

Volcanic rocks, consisting of fine tuffs, associated with radiolarian chert, occur at certain localities. The fine tuffs at Trowdale, near Castle-Douglas, may belong to Lower Llandeilo time, and the (ashy) mudstones found in Craigmichan Scaurs seem to be composed partly of volcanic materials.

Fossils.—The cherts of Lower Llandeilo age, as well as those

interbedded with the Glenkiln black shales, are abundantly charged with radiolaria.

The Upper Llandeilo Rocks (Glenkiln Shales) possess a characteristic assemblage of graptolites which differs in a marked degree from that recorded from the Arenig Rocks of the region. Indeed, only two of the Scottish genera (*Didymograptus* and *Climacograptus*) pass upwards from the Arenig to the Upper Llandeilo horizon. It is a remarkable fact that *Didymograptus Murchisoni*, which is the zonal form of the Lower Llandeilo Rocks of Wales and other regions, has not been detected throughout the length and breadth of the Southern Uplands. Its absence, however, may be accounted for on the supposition that the Lower Llandeilo Rocks are, in the South of Scotland, represented by the upper part of the zone of radiolarian chert, which intervenes between the Middle Arenig black shales and the Glenkiln black shales.

The zonal graptolite of the Glenkiln Shales is *Cœnograptus gracilis*, which is associated with the following genera: *Didymograptus*, 2 species; *Thamnograptus*, 2; *Clathrograptus*, 1; *Dicranograptus*, 7; *Dicellograptus*, 6; *Leptograptus*, 1; *Diplograptus*, 6; *Cryptograptus*, 1; *Glossograptus*, 1; *Lasiograptus*, 2; *Climacograptus*, 3; *Corynoides*, 2. (Plate XXVI.)

The number of genera and species of hingeless brachiopods is limited, compared with those occurring in the mudstones which immediately overlie the Arenig volcanic rocks. They are restricted to the genera *Acrotreta*, *Acrothele*, *Siphonotreta*, and *Discina*. The glass-rope sponge (*Hyalostelia*) is also recorded from this horizon.

Conditions of Deposition.—In Lower Llandeilo time, oceanic conditions prevailed during the accumulation of the radiolarian ooze in the central region, save at certain localities where, owing probably to the elevation of the sea-floor, the area of deposition was brought within the limit of terrigenous sedimentation. In Upper Llandeilo time, the sea-floor must have remained for a long interval sufficiently deep and far from land to permit the fine sediment to accumulate, in which the graptolites and hingeless brachiopods were entombed. The zone of orange-coloured mudstones and radiolarian cherts indicates a recurrence of oceanic conditions with clear water, followed by the deposition of fine dark mud which now forms the few feet of black shale at the base of the Hartfell shales.

NORTHERN BELT.

Rocks.—The Lower Llandeilo Rocks are here represented, as in the central area, by the upper portion of the zone of radiolarian chert, which intervenes between the Arenig volcanic rocks and the Glenkiln Shales (Upper Llandeilo). In a few exceptional localities (Tannylaggie, Glen Trool, Waterhead) the cherts are apparently intercalated with greywackes in such a way as to preclude the supposition that the relationship is due to faulting.

In the case of the Upper Llandeilo group there is conclusive evidence of the gradual change in the character of the sedimentation as we pass towards the northern margin of the tableland and westwards towards Girvan. Over much of the area, however, the Upper Llandeilo Rocks are represented by black shales of the normal Glenkiln type in the Moffat region. Indeed, throughout the various anticlines of the Moffat series, which are traceable along the southern portion of the Northern Belt, as, for example, from Morroch Bay, south of Portpatrick, north-eastwards by Glen Trool, Carsphairn, and Sanquhar, thence by the Lead Hills and Abington to the Moorfoot Hills and the northern slopes of the Lammermuirs, there is little variation in the lithological characters of the Upper Llandeilo Rocks. They consist of a mass of black shales with thin black siliceous ribs or flinty bands from one to several inches thick. But to the north of this limit a marked change is observable. For instance, in Cowie's Linn Burn, north of Eddleston, in the county of Peebles, the strata yielding the Glenkiln fauna (Upper Llandeilo) no longer consist of a solid mass of black shales, but are composed either of dark sandy micaceous shales interleaved in grey shales, or of dark rusty bands embedded in green and grey mudstones.

Similar modifications are observable along the margin of the tableland from Leadburn to the valley of the Clyde north of Abington, where, in some instances, the black shales disappear altogether and sediments of a different type rest directly on the radiolarian cherts. One example may be quoted to show how rapidly the change takes place within a short horizontal distance. In the Wandel Water, north-east of Abington, below Birnock shepherd's house, black shales of the normal Moffat type appear, with the characteristic Glenkiln fauna, while about two miles across the strike, in the River Clyde near Wandel Mill, the same fossils occur in dark films in sandy shales and greywackes. Again, in the Fingland Burn—a tributary of the Spango Water, north-east of the Sanquhar coal-field—the Glenkiln fauna appears in dark seams, from one-tenth of an inch to an inch thick, interleaved in sandy shales.

Crossing the Nith and proceeding along the northern border of the tableland, we find similar phenomena, as, for instance, at Craiglure Lodge, near the head waters of the River Girvan, where the characteristic Glenkiln fossils can be obtained from minute dark seams in sandy shales, embedded in massive greywackes and grits.

In the south-western portion of the Northern Belt, in the neighbourhood of New Luce and Loch Ryan, the change in the character of the sedimentation of the Upper Llandeilo Rocks extends much further south than in the districts just referred to. Indeed, it is clearly recognisable in the Main Water of Luce, about two miles north of New Luce, where, at the south end of an important section, the Glenkiln fossils occur in massive, flaggy black shales. while at the north end of the same

section they appear in minute streaks of blue-black shales embedded in grey shales. Still further north, in the Cairn Ryan slate quarries, on the east side of Loch Ryan, at the mouth of Glen App, and in the neighbourhood of Barrhill, a characteristic assemblage of Glenkiln fossils has been collected from thin dark carbonaceous seams or films, interleaved in grey and blue shales and slates, the latter being associated with greywackes.

It is obvious, therefore, that some of the coarser sediments (shales, flagstones, greywackes, and grits) which replace the Glenkiln black shales in the Northern Belt must be of Upper Llandeilo age. Indeed, one of the difficulties resulting from the lateral variation in the phase of sedimentation in this northern area is that of fixing the upper limit of the coarser sediments of Llandeilo age, for many of these unfossiliferous Llandeilo grits are lithologically indistinguishable from certain grits which are believed to be Caradoc.

Some of the pebbly grits along the northern margin of the tableland are probably Upper Llandeilo, and the coarse conglomerate of Corsewall Point west of Loch Ryan, which is believed to be on the horizon of the Benan conglomerate of the Girvan district, may belong to the close of Upper Llandeilo time.

Some of the volcanic rocks in the Bail Hill area, near Sanquhar, may be of Upper Llandeilo age.

Fossils.—All the characteristic graptolites of the Glenkiln Shales (Upper Llandeilo) of the Moffat region have been recorded from the black shales occupying a similar horizon in the Northern Belt. And even where these strata are replaced by coarser sediments, many, if not most, of the characteristic Glenkiln forms occur in the thin films interleaved in the grey shales and greywackes. It is interesting to observe that in addition to these forms, *Loganograptus Logani*, a graptolite which elsewhere occurs in Arenig Rocks, together with *Dendrograptus*, appears in the Abington and Leadhills region in black shales of Upper Llandeilo age. The graptolites are associated with some of the genera of hingeless brachiopods found in the Glenkiln Shales of the Central Belt.

Conditions of Deposition.—The black shales point to conditions of deposition near the verge of sedimentation, but the gradual replacement of these fine sediments by coarser deposits as we proceed northwards clearly indicates that the land surface from which these materials were derived lay to the north-west of the Silurian sea.

GIRVAN AREA.

Rocks.—As in other districts of the Southern Uplands, the Lower Llandeilo Rocks are here represented by radiolarian cherts and mudstones, being the upper portion of the zone which overlies the black shales of Middle Arenig age. In one important section on the shore near Port-Currarie, between the River

Stinchar and Glen App, the radiolarian cherts and mudstones are overlain by volcanic agglomerate and tuff, the latter being immediately followed by mudstones yielding a characteristic assemblage of Glenkiln fossils (Upper Llandeilo). It is obvious, therefore, that volcanic action must have here continued locally into Lower Llandeilo time.

In dealing with the Upper Llandeilo Rocks of the Girvan area, we must clearly distinguish between the district lying to the south of the River Stinchar, where there is a perfect passage from the Arenig lavas and tuffs to certain mudstones and other sediments which yield many of the characteristic Glenkiln fossils (Upper Llandeilo), and the district to the north of the Stinchar, where there is a marked unconformability, separating the Arenig volcanic rocks and radiolarian cherts from the overlying sedimentary series of Girvan. From a consideration of the palæontological evidence it is highly probable that this break in the continuity of the geological record north of the Stinchar valley took place in Upper Llandeilo time.

Taking first the Upper Llandeilo sediments south of the Stinchar valley, we find them to consist of green, grey, and blue-black fossiliferous mudstones (Currarie, Portandea) followed by green and grey mudstones, shales, and friable greywackes, the latter being largely derived from the disintegration of volcanic and plutonic rocks (the Tappins group). In the pebbly grits associated with the "Tappins beds," there are small fragments of radiolarian chert and volcanic rocks. In like manner the Glen App conglomerate, which appears to be intercalated in the higher part of the same series, presents an assemblage of pebbles, almost identical with those met with in the Benan conglomerate to be referred to presently. Indeed, these coarse boulder-beds of Corsewall Point, Glen App, and Benan, north of the Stinchar, are all believed to occupy much the same horizon.

North of the Stinchar valley there is a vast difference in the character of the Upper Llandeilo Rocks, owing to the presence of the prominent discordance to which allusion has just been made. Beneath the unconformable series no fossiliferous representatives of the Glenkiln Shales have as yet been detected. It is true that near Bennane Head certain green and grey mudstones and greywackes overlie the radiolarian cherts (Arenig and Lower Llandeilo), but they have hitherto proved unfossiliferous.

Those members of the unconformable series which are here regarded as of Upper Llandeilo age are, in ascending order, (a) Kirkland conglomerate and sandstones, (b) Stinchar limestone, (c) Graptolitic mudstones, (d) Benan conglomerate; which not only rest unconformably on the folded and highly denuded surfaces of the Arenig volcanic and plutonic rocks, the Arenig black shales and radiolarian cherts, but likewise contain well-rounded pebbles and fragments of these very materials.

Fossils.—The fossils occurring in the mudstones, of Upper Llandeilo age, which overlie the Arenig volcanic rocks and cherts south of the valley of the Stinchar (Portandea, Currarie) consist

mainly of graptolites, with a marked Glenkiln facies, such as *Didymograptus superstes*, *Cœnograptus pertenuis*, *Dicranograptus minimus*, *Climacograptus cælatus*. Special interest, however, attaches to this horizon from the abundance of specimens of *Dendrograptus gracilis* in the section 600 yards north of Port-Currarie (see page 429), where, in addition to the characteristic Glenkiln forms, this species is associated with a *Callograptus* like *C. Salteri* and a *Didymograptus* like *D. extensus*. Hingeless brachiopods, including the forms in the Glenkiln shales of the Central Belt, together with the genera *Siphonotreta* and *Kutorgina*, are likewise found in these mudstones.

In the Upper Llandeilo Rocks on the north side of the Stinchar valley the marked change in the lithology of the strata is accompanied by a no less conspicuous change in the facies of the fossils. Here for the first time we find, as in the case of the Stinchar Limestone, a prolific assemblage of calcareous organisms, indicating an entire difference in the character of the sedimentation.

A conspicuous feature of the limestone is the abundance of those organisms forming irregular nodules, with concentric structure, named *Girvanella*, which are now believed to have affinities with the calcareous Algæ. In certain bands *Foraminifera* enter largely into the composition of the limestone, the forms all belonging to one species, viz.: *Saccamina Carteri*, which is likewise found in abundance in some of the Scottish Carboniferous limestones. Corals are in great profusion in some of the limestone exposures, as at Craighead. No fewer than seventeen genera have been recorded from all the outcrops of this band in the Girvan region, including *Chœtetes*, *Favosites*, *Halysites*, *Lindströmia*, *Streptelasma*, *Stenopora*, *Tetradium*, &c.

In the Monograph on the Silurian Fossils of Girvan (page 94), Professor Nicholson states that "*Lyopora favosa*, *Tetradium Peachi*, *Prasopora Grayæ*, *Streptelasma Craigense*, *S. Europæum*, *S. aggregatum*, and *Lindströmia subduplicata* are the common forms of the Craighead Limestone, and, with the exception of the last, they are not known to occur elsewhere in Britain." Since the publication of this work, *Lyopora favosa* has been recorded from the Kilbucho grit and *Lindströmia subduplicata* from the beds at Wallace's Cast and Kilbucho. Judging only from the corals, Professor Nicholson inferred that the Craighead Limestone "occupies a tolerably low position in the Lower Silurian series, corresponding perhaps with the upper part of the Trenton Limestone, or the base of the Cincinnati and Hudson River formations of North America."

The echinoderms are poorly developed in these Upper Llandeilo limestones, the only prominent form being *Glyptocrinus*. The arthropods, on the other hand, are found in abundance; the cirripedes being represented by *Turrilepas*, the ostracods by the genera *Cythere* and *Primitia*, while no fewer than fourteen genera of trilobites have been obtained from this horizon, including

Ampyx, 1 species; *Calymene*, 1; *Asaphus*, 2; *Cheirurus*, 2; *Illænus*, 4; *Encrinurus*, 1; *Phacops*, 1; *Remopleurides*, 4; &c.

The calcareous brachiopods, which likewise occur in profusion in the limestone zones, comprise seven genera, including *Leptæna*, 9 species; *Meristella*, 1; *Orthis*, 15; *Strophomena*, 9; *Rhynchonella*, 11. The lamellibranchs number three genera, viz.: *Ambonychia*, 2 species; *Orthonota*, 1; *Pleurorhynchus*, 1. The gasteropods comprise thirteen genera, including *Maclurea*, 5 species; *Ophileta*, 1; *Murchisonia*, 5; *Pleurotomaria*, 2. The cephalopods are represented by three genera, viz.: *Cyrtoceras*, 2 species; *Orthoceras*, 3; *Trocholites*, 1.

Besides other forms of calcareous organisms, a few genera of horny brachiopods likewise occur, but chiefly in the graptolitic mudstones overlying the limestone, viz.: *Acrotreta*, 1 species; *Crania*, 2; *Discina*; *Lingula*, 5; *Siphonotreta*, 3. These are associated with several genera of graptolites; some of the forms (*Didymograptus superstes*, *Diplograptus euglyphus*, and *Clathrograptus cuneiformis*) having a marked Glenkiln facies, while others are common both to the Glenkiln and Hartfell groups of the Moffat region. Professor Lapworth has called attention to the bearing of this evidence on the horizon of the Stinchar and Craighead Limestone. While agreeing with him in regarding it as of Upper Llandeilo age, we are inclined to believe that it may belong to the close of that division of the Silurian system; for though some of the corals and some of the genera of the gasteropods (*Maclurea*, *Ophileta*) have a Llandeilo facies, the other groups of organisms have a marked Caradoc character.

Conditions of Deposition.—While the deposits to the south of the River Stinchar imply continuous sedimentation in Upper Llandeilo time, the conditions seem to have been on the whole unfavourable for the development and preservation of life. The lithological characters of the "Tappins beds" and of the Glen App conglomerate point to the erosion of Arenig igneous rocks at no great distance.

On the other hand, the evidence obtained from the north side of the Stinchar points to considerable disturbance and elevation of that area, whereby the cherts and any overlying sediments were removed by denudation, and the volcanic and plutonic rocks were laid bare. The coarse conglomerates (Kirkland and Benan) represent the shore deposits which accumulated round that ancient volcanic bank as it slowly subsided, while the limestones reveal to us the calcareous organic sediment furnished by a rich and varied fauna that flourished near the margin of the Silurian sea.

CARADOC.

CENTRAL BELT.

Rocks.—The Hartfell Shales, which in the Central Belt represent the Caradoc Rocks of Wales, may be grouped in two sub-divisions, each characterised by distinct lithological

characters: (a) a lower tolerably solid mass of slaty black shales with thin intercalations of pale mudstones, (b) an upper group of fine mudstones (Barren Mudstones), containing thin ribs of limestone and chert, nodules of ironstone and manganese, and two or more thin seams of black shale. In the Hartfell section thin seams of tuff are interleaved in the black shales of the lower group, and a band of volcanic breccia is met with in the mudstones of the overlying group.

Though the foregoing sub-divisions of the Hartfell Shales generally preserve their lithological characters throughout the various anticlines of the Moffat series, still, in one section (Ettrickbridge-end), coarse grits appear near the top of the Barren Mudstones.

Fossils.—As in the black shales of the underlying Glenkiln division, graptolites form the distinctive group of organisms in the black shales of the Hartfell series. Professor Lapworth states that, while there is no actual palæontological break between the Glenkiln and Hartfell divisions,* "the fossils of the lower division die out one by one as we ascend the succession, and are as gradually replaced by others till the change of fauna is complete. Thus, although the two successive faunas are linked together by a large community of genera and species, yet, on the other hand, the typical beds of the two formations have scarcely a single fossil in common. At the summit of the Hartfell Shales, on the contrary, the palæontological break is almost complete . . . . . .

"There is an extraordinary mortality among the graptolites in this division. Not only do the peculiar types *Pleurograptus* and *Amphigraptus* arise, culminate, and decay within the formation itself, but *Dicellograptus*, *Dicranograptus*, *Lasiograptus*, *Glossograptus*, and *Leptograptus*—survivors from the Glenkiln Shales—all become extinct before we reach the highest beds. The allied genera *Climacograptus* and *Diplograptus* are all that remain to link on the richly varied forms of the Glenkiln beds to the highly prolific but monotonous fauna of the Birkhill Shales." The zonal graptolite forms of the Hartfell strata are as follows, in descending order:—

	Upper Group.
Dicellograptus anceps	in thin black shale seam near top of Barren Mudstones.
,, *complanatus*	in thin black shale seam near base of Barren Mudstones.
	Lower Group.
Pleurograptus linearis *Dicranograptus Clingani* *Climacograptus Wilsoni*	in Hartfell black shales.

The Lower Hartfell fauna is further characterised by the great abundance on different horizons of the genera *Dicellograptus*, *Dicranograptus*, *Diplograptus*, *Pleurograptus*, and *Corynoides*. In

* The Moffat Series. Quart. Jour. Geol. Soc. Vol. XXXIV., p. 307.

the case of *Dicellograptus*, for example—a survivor from the Glenkiln fauna—where it has a restricted development, Professor Lapworth truly says that in one zone of the Hartfell Shales "its individuals swarm in countless multitudes." (Plate XXVII.)

The rare form *Buthograptus laxus* is confined to the *Climacograptus Wilsoni* zone in the Moffat region, where it is associated with numerous representatives of the glass-rope sponge, *Hyalostelia*.

Two genera of hingeless brachiopods—viz., *Acrotreta* and *Siphonotreta*—are of common occurrence in the Hartfell division.

Conditions of Deposition.—In Lower Caradoc time the sea-floor throughout the central region must have remained at a sufficient depth and far enough from land to permit the fine sediment to accumulate in which the graptolites were entombed.

In Upper Caradoc time the phase of sedimentation implied by the Barren Mudstones probably points to a further depression of the sea-floor of the central region. For the physical conditions, including distance from land and depth of ocean, were probably intermediate between those which characterised the deposition of the black shales on the one hand and the radiolarian ooze on the other.

The thin seams of tuff and volcanic breccia likewise indicate sporadic outbursts of volcanic activity over the Central Belt.

NORTHERN BELT.

In this portion of the tableland there is conclusive evidence of the lateral variation in the character of the Caradoc strata as they are traced northwards towards its margin and westwards to Girvan.

Rocks.—Taking first the mass of black shales which in the Central Belt form the lower sub-division of the Hartfell group, we find it repeated in many of the anticlines of the Moffat series, along the southern portion of the Northern Belt, where it presents the normal lithological and palæontological features which have just been described. For example, in the sections in Morroch Bay, south of Portpatrick, in the Scar Water and some of its tributaries which flow into the Nith, and again at the Friar's Nose on the slopes of the Lammermuirs, the Hartfell black shales possess their distinctive lithological characters and yield many of the zonal forms which occur in the Central Belt. But as they are followed northwards the black shales are gradually replaced by coarser sediments, and the characteristic graptolites appear, either in thin black seams interleaved in flaggy shales or in dark sandy shales. Indeed, the lateral variation in the lithological characters of the Hartfell black shales in the Northern Belt is merely the counterpart of that presented by the Glenkiln Shales, with this slight difference, that the change in the character of the sedimentation extends much further south in the case of the Hartfell black shales.

Various examples might be quoted for the purpose of illustrating this striking modification of the Hartfell black shales, but one or two may suffice. In the case of the black

shale band which stretches from Burnmouth on the Nith to Dalshangan on the River Deugh, the lithological and palæontological features of the *Dicranograptus Clingani* zone of the Hartfell Shales are admirably represented, but when traced northwards to the Polmorlach and Polhote Burns, within two miles of the margin of the tableland at New Cumnock, this band with its zonal forms is found to have disappeared. Thin black seams are there seen to be interleaved in blue and grey shales, which are charged with forms characteristic of the passage zone between the Glenkiln and Hartfell groups. (See page 369.) Confirmatory evidence of this change in the sedimentation, within a short horizontal distance, is to be found in the Glencaple Burn, south-west of Abington. (See page 289.) In like manner, in the Polcraig Burn, Meikle Carco, a characteristic Lower Hartfell form, *Climacograptus caudatus*, with many of its associates, is found in brown sandy shales.

The coarse sediments which gradually replace the Hartfell black shales in certain areas of the Northern Belt, and which may, in all probability, be regarded as their stratigraphical equivalents, are here given in ascending order: 1, dark micaceous shales, with black seams yielding graptolites, which frequently decompose into a yellowish brown ochreous clay; 2, grey greywackes, grits, and conglomerates, with limestone nodules and calcareous shales, which at certain localities in the Leadhills, Abington, and Broughton districts (Duntercleuch, Snar, Wallace's Cast, Kilbucho) are highly fossiliferous.

Frequently these sediments merge into coarse conglomerates, as, for instance, in the Shinnel and Chanlock Waters, north of Moniaive, on the hills near Carsphairn, and in the basin of the Afton Water, where the pebbles consist of acid and basic plutonic rocks, vesicular diabase-lava, radiolarian chert, blue and grey greywacke, grey shale, black shale with graptolites, quartzite from the Highlands, and other ingredients.

In certain districts of the Northern Belt, especially in the tract between Nithsdale and the valley of the Clyde at Abington, there is evidence of local elevation and erosion of the Arenig and Llandeilo Rocks. Various examples are given in the section of this memoir descriptive of the foregoing area, but one may here be quoted to show the nature of the evidence. In the Glenaylmer Burn, near the northern margin of the tableland, north of Sanquhar, there is an excellent section, showing the Arenig cherts with radiolaria covered unconformably by breccia and conglomerate, passing upwards into greywackes and shales. The basal breccia contains angular fragments of chert and black and grey shale, while the overlying conglomerate includes pebbles of greywacke, the largest of which measure nine inches in diameter. There can be no doubt that these materials are of local origin, and it is highly probable that this local elevation and erosion took place towards the close of Llandeilo time.

Along the northern margin of the tableland, from Loch Doon north-eastwards by Kirkconnel, Crawfordjohn, and the Culter

Water to Leadburn, there is a remarkable pebbly grit or fine conglomerate which is locally known as the "Haggis Rock." Its distinctive character is due to the presence of small fragments of red, green, and grey radiolarian cherts, and Arenig volcanic and plutonic rocks, while the matrix has been mainly derived from the disintegration of these igneous materials. The precise stratigraphical horizon of this band is not quite clear, for in that northern region the Hartfell black shales have disappeared, and even the Glenkiln black shales have been so modified that their characteristic forms are found in thin blue-black films interleaved in other sediments. In some instances, as, for example, near Fingland, between the Spango granite mass and Kirkconnel, the "Haggis Rock" overlies sediments yielding Glenkiln fossils (Upper Llandeilo); in others, no Glenkiln graptolites have been obtained from the strata which intervene between this band and the radiolarian cherts. While in many of the horizontal sections in this volume the "Haggis Rock" of this northern region is represented as of Caradoc age, it is highly probable that bands of a similar petrological type may belong to a lower stratigraphical horizon.

In certain isolated sections in the Leadhills area and in the district south-west of Sanquhar (Craig North, Kiln Burn, Nether Whitecleuch, Shields Burn, Glengap Burn, Polmorlach Burn), diabase-lavas and andesitic tuffs appear at or near the base of the Caradoc Rocks.

The upper division of the Caradoc Rocks of the Northern Belt indicates a great variation from the lithological type of the Barren Mudstones of the central Moffat region, for they consist of grey and blue micaceous shales weathering with a buff colour (Lowther Shales), blue and grey slates (Stobo Slates), with occasional greywackes and grits. A notable feature of this sub-division is the occurrence of limestone nodules in the shales, which sometimes coalesce so as to form a continuous band and sometimes swell out locally into lenticular masses of limestone, as at Wrae and Glencotho, the latter yielding a considerable suite of fossils. These are associated with calcareous grits which yield a similar assemblage of organic remains.

Perhaps one of the most striking features of the Upper Caradoc Rocks of the Northern Belt is the occurrence of contemporaneous lavas and tuffs with the limestone and calcareous grits at Wrae, Glencotho, Hamilton Hill, and Winkston in the county of Peebles. Mr. Teall has shown that the lavas are of different petrographical types from those of Arenig age in the Southern Uplands, since they consist of soda-felsites or keratophyres and perlitic felsites. The development of these volcanic rocks is, however, merely local: at least they are traceable only over a very limited area. Their horizon is defined by the occurrence of Caradoc fossils in the calcareous tuff associated with the limestone, just as organic remains are embedded in the volcanic ash of Caradoc age on Snowdon, North Wales

Fossils.—The Lower Hartfell black shales of the Northern Belt yield nearly all the characteristic graptolites and hingeless brachiopods which have been found in the same sub-division in the central region. Two zonal forms, however, have not been recorded, so far as we know, from any portion of the Northern Belt, viz.: *Climacograptus Wilsoni*, which characterises the lowest sub-zone of the Hartfell black shales, and *Dicellograptus anceps*, which is the distinctive form of the black shale seam near the top of the Barren Mudstones, in the Moffat region. Where the black shales disappear and are replaced by coarser sediments (shales and flagstones) with thin dark seams or films containing graptolites, common to the Hartfell and Glenkiln divisions, considerable difficulty has been experienced in fixing the horizon of the latter strata. Indeed, in some instances, as, for example, in that of the Dally Shales in Dounan Bay, south of Corsewall Lighthouse, Wigtownshire, which yield the following forms: *Diplograptus foliaceus*, *D. euglyphus*, *Climacograptus Schärenbergi*, *C. bicornis*, *Dicranograptus ramosus*, *Dicellograptus sextans*, *D. divaricatus*, the stratigraphical horizon of the strata is not quite clear. Provisionally, they are regarded as the passage beds between the Llandeilo and Caradoc groups, but further careful searching of the fossiliferous seams will doubtless throw light on this question.

In addition to the foregoing types of life, calcareous organisms occur in considerable abundance in the coarser sediments, which accumulated round the areas of local elevation and erosion, as, for example, in the Leadhills and Abington districts. An analysis of the lists of fossils collected from various exposures of grit and conglomerate at Kilbucho, Wallace's Cast, and in the Leadhills region, reveals the following results. Corals are represented by eleven genera, including *Alveolites*; *Favosites*, 4 species; *Lindströmia*, 3; *Petraia*, 3; *Tetradium*, 2; *Heliolites*, 1. There are four genera of polyzoa, comprising *Ptilodictya*, *Fenestella*, *Ceriopora*. Trilobites number six genera, viz.: *Calymene*, 1; *Cheirurus*, 2; *Illænus*, 1; *Phacops*, 3; *Remopleurides*, 3; *Trinucleus*, 1. (For complete lists see pp. 225, 243, 324.)

The calcareous brachiopods are represented by six genera, including *Leptæna*, 5 species; *Orthis*, 13; *Rhynchonella*, 4; *Strophomena*, 8—all of which have a marked Caradoc facies. Indeed, in the "Supplement to the British Silurian Brachiopoda," page 229, Mr. Davidson refers the strata yielding brachiopods from these localities to the Caradoc group. The lamellibranchs number three genera, viz.: *Ctenodonta*, 2 species; *Modiolopsis*, 2; &c.; while the gasteropods comprise no fewer than twelve genera, including *Bellerophon*, 4 species; *Chelodes*, 1; *Cyclonema*, 1; *Macrocheilus*, 1; *Murchisonia*, 3; *Ophileta*, 1; *Pleurotomaria*, 3. The cephalopods are represented by two genera, viz.: *Cyrtoceras*, 1 species, and *Orthoceras*, 1.

The organic remains obtained from the limestones, calcareous grits, and volcanic tuff at Wrae, Glencotho, Winkston, and Hamilton Hill, which are referred to Upper Caradoc time, have

a common general character, and belong, without doubt, to one horizon. The crinoids are represented by *Glyptocrinus*, the cirripedes by *Turrilepas;* while the trilobites number several genera, including *Cheirurus*, 3 species; *Harpes*, 1; *Illænus*, 3; *Phacops*, 1. No fewer than eleven genera of brachiopods have been obtained from this horizon, among which occur *Leptæna*, 3 species; *Orthis*, 6; *Rhynchonella*, 1; *Strophomena*, 3. Only one genus of lamellibranchs has hitherto been recorded from this horizon (*Orthonota*); four genera of gasteropods have been obtained, among which occur *Cyclonema*, *Euomphalus*, *Holopea*; and four genera of cephalopods.

Conditions of Deposition.—The lower Hartfell black shales, which extend over a portion of the Northern Belt, point to the accumulation of fine mud near the verge of sedimentation —conditions similar to those which prevailed throughout the Central Moffat area during this period. But there is also conclusive evidence of the transport of coarse sediment from the ancient land area which lay to the north-west of the Silurian sea, whereby each successive sub-division of the Hartfell group of the Moffat region was modified in turn. It is a remarkable fact that the change in the character of the sedimentation resulting from the transport of coarse terrigenous material from the north-west extends further south with each successive period. For example, the modification of the Moffat type of the Hartfell black shales extends further south throughout the length and breadth of the Northern Belt than that of the Glenkiln Shales, while the change in the character of the Barren Mudstones extends further south than that of the underlying Hartfell black shales. In the sequel it will be shown that similar phenomena are characteristic of the overlying Llandovery Rocks.

There is evidence also of small areas of local elevation and erosion whereby Llandeilo and other rocks were removed and the materials were redeposited in the overlying sediments.

Towards the close of Llandeilo and near the beginning of Caradoc time a few thin sheets of diabase-lava and andesite-tuff were discharged from isolated vents and buried underneath graptolitic mud and other sediment. The closing phase of volcanic activity in the Silurian rocks of the Southern Uplands is represented by the soda-felsite and perlitic felsite-lavas and tuffs which were locally erupted during Upper Caradoc time, many of the calcareous organisms having been entombed in the ash which covered part of the sea-floor.

GIRVAN AREA.

Rocks.—The Caradoc Rocks of the Girvan area indicate a complete change in the phases of sedimentation from those which obtained in the central Moffat area during the same period. Here thick masses of sediment consisting of conglomerates, grits, greywackes, flagstones, mudstones, shales, and limestones are associated with finer materials, which yield graptolites characteristic of the Hartfell division of the Moffat series. In this region these rocks comprise the various divisions of the

Ardmillan series established by Professor Lapworth and given here in descending order, to which have been added the Balclatchie beds:

Drummuck Group,	Grey fossiliferous mudstones and occasional flagstones.
Barren Flagstone Group,	Flagstones and shales usually unfossiliferous.
Whitehouse Group,	Red and green mudstones, with grey and black shales and limestones.
Ardwell Group,	Dark grey flaggy shales, with carbonaceous shales and bands of coarse pebbly grit.
Balclatchie Group,	Conglomerates, grits, and fossiliferous mudstones.

It is rather remarkable that the strata forming the highest sub-division of the Caradoc Rocks of Girvan (Drummuck group) are represented only in the Craighead inlier, north of the Girvan valley. They do not intervene between the Barren Flagstones and the overlying Llandovery strata on the south side of that river—a structural feature which will be referred to in the sequel.

Fossils.—The assemblage of organic remains in the Caradoc Rocks of Girvan is similar to that found in strata of the same period in the Northern Belt, with this difference, that the fauna is richer both in genera and species.

One of the most prolific horizons in these Caradoc Rocks, and indeed in the whole Girvan succession, is the zone of mudstones intercalated in the grits of the Balclatchie group, which group is regarded by Professor Lapworth as forming the passage beds between the underlying Barr series and the overlying Ardmillan series. The polyzoa are represented by three genera: (*Ptilodictya*, &c.); the cirripedes by *Turrilepas*, and the phyllopod crustaceans by *Pinnocaris*. One of the characteristic palæontological features of this horizon is the profusion of trilobites, there being no fewer than twenty-one genera, including *Acidaspis*, 3 species; *Agnostus*, 1; *Barrandia*, 1; *Ampyx*, 6; *Asaphus*, 1; *Bronteus*, 1; *Bronteopsis*, 1; *Cheirurus*, 4; *Cybele*, 2; *Deiphon*, 1; *Illænus*, 3; *Harpes*, 1; *Lichas*, 3; *Phacops*, 1; *Proetus*, 1; *Remopleurides*, 2; *Salteria*, 1; *Stygina*, 1; *Sphærexochus*, 1; *Staurocephalus*, 2; *Trinucleus*, 3; &c. Of the brachiopods there are eleven genera, of the lamellibranchs 7, of the gasteropods 10, and of the cephalopods 5 genera.

There are four genera of graptolites found in these Balclatchie mudstones, viz.: *Dicranograptus*, *Dicellograptus*, *Diplograptus*, and *Climacograptus*; the species being common to the Glenkiln and Hartfell divisions of the Moffat series.

In the overlying Ardwell group various seams yield graptolites more or less characteristic of the lower sub-zones of the Hartfell

black shales, as, for instance, *Climacograptus caudatus* in the flaggy shales near the top of the group on the shore at Ardwell.

An abundant fauna, partly graptolitic and partly calcareous, has been obtained from the members of the Whitehouse group. For the purpose of correlating the strata with those of the Central Belt, the occurrence here of the two zonal graptolites, *Pleurograptus linearis*, characteristic of the highest sub-zone of the Hartfell black shales, and *Dicellograptus complanatus*, of the lower portion of the Barren Mudstones, is of great interest.

Among the calcareous organisms, the corals are represented by *Halysites*; the polyzoa by the genus *Fenestella*; and the crinoids by *Glyptocrinus*. The annelides include the genera *Serpulites* and *Tentaculites*. Among the crustaceans, the cirripedes are represented by *Turrilepas*, and the ostracods by six genera, viz.: *Aparchites*, 2 species; *Beyrichia*, 2; *Cypridina*, 1; *Primitia*, 5; *Ulrichia*, 2; *Sulcuna*, 2. The trilobites number 11 genera, brachiopods 11, lamellibranchs 2, gasteropods 10.

The Barren Flagstone group, which overlies the Whitehouse beds, is remarkably destitute of fossils, but the mudstones, which constitute the dominant feature of the highest division of the Caradoc Rocks of Girvan (Drummuck), have yielded a large assemblage of organic remains. Indeed, they have become widely known from the abundance and excellent preservation of the trilobites, there being no fewer than thirteen genera, including *Ampyx*, 1 species; *Calymene*, 2; *Cheirurus*, 2; *Cybele*, 1; *Dionide*, 1; *Dindymene*, 1; *Illænus*, 2; *Lichas*, 2; *Phillipsia*, 1; *Phacops*, 1; *Proetus*, 3; *Staurocephalus*, 1; *Trinucleus*, 3. While the species of trilobites have a marked Upper Bala facies, there are some points of considerable interest connected with the distribution in time of some of the forms. For example, the genus *Phillipsia*, which here makes its first appearance in the Silurian succession of the Southern Uplands, passes upwards into the Lower Carboniferous series; while *Phacops Brongniarti*, which is a characteristic fossil of the Stinchar Limestone, does not occur on any higher horizon. The brachiopods number 9 genera, the lamellibranchs 2, the gasteropods 14, the pteropods 3, the cephalopods 2.

Professor Lapworth has identified a specimen of *Dicellograptus anceps*, obtained by Mrs. Gray from the Drummuck mudstones—the characteristic graptolite of the upper portion of the Barren Mudstones of the Moffat region.

Another interesting palæontological feature of the Caradoc Rocks of Girvan is the occurrence of a star-fish band at the very top of the series which has been made known through the researches of Mrs. Gray and Professor Lapworth. The star-fishes, which occur in considerable abundance, are referable to *Tetraster Wyville-Thomsoni*, and are associated with many representatives of the various groups of organisms occurring in the underlying mudstones.

Conditions of Deposition.—The sequence of Caradoc Rocks in the Girvan region points to the existence of an extensive land-surface to the north of the Silurian sea. The strata

represent shore-deposits which were accumulated on a gradually subsiding area, and an analysis of the fossil lists clearly proves that trilobites, brachiopods, and gasteropods must have swarmed in these shallow seas. But here, as elsewhere, the close of this period is marked by a great change in the life-history of the system. All the species of graptolites found in the Caradoc Rocks of Girvan disappear, and only the genera *Diplograptus*, *Climacograptus*, and *Retiolites* pass up into the Llandovery formation. At this horizon also there is a striking change in the genera and species of the other life-groups, thus clearly indicating that, though no marked unconformability is traceable, there is nevertheless a distinct palæontological break.

UPPER SILURIAN.

LLANDOVERY AND TARANNON.

CENTRAL BELT.

Rocks.—We have now reached an important stage in the history of the Silurian rocks of the Southern Uplands, for not only is there a marked change in the fauna when we cross the threshold of the Upper Silurian system, but there is also evidence that, while oceanic conditions of deposition prevailed over a large part of the Central Belt in Llandovery time, the coarse terrigenous materials were carried further south, till in Tarannon time they overspread the sea-floor of the whole central region.

In the Moffat region of the Central Belt the Llandovery Rocks are represented by the Birkhill Shales, divisible into two groups, a lower, composed of black flaggy shales, which near the top contains seams of clay with nodules and ribs of limestone, and an upper group of alternations of black and grey shales and mudstones, with abundant seams of white clay. Though they are lithologically connected with the underlying Hartfell and Glenkiln Shales, having been deposited under somewhat similar conditions, they are readily distinguishable in the field by the numerous seams of white clay and the peculiar character of the black shales. In one of the zones, that of *Monograptus gregarius*, in the typical Dobb's Linn section, there is a band of black grit intercalated in the finer sediments. Such are the lithological divisions of the Birkhill Shales in many of the anticlines along the strike of the Dobb's Linn fold in the central Moffat region.

Professor Lapworth showed that as the observer passes north-westwards from the central Moffat region, the Birkhill Shales are modified and replaced by other sediments—that, for example, in the Hartfell section to the north-west of the strike of the Dobb's Linn anticline, the upper division of the Birkhill Shales has disappeared. In like manner the highest sub-zone of the lower division *(Monograptus gregarius)* is no longer met with in the arch at Cow Linn in the Fruid Water, and when the bands are traced north to the junction of that stream with the

River Tweed, the lower division is represented by blue-black seams in other sediments, from which one or two zonal forms have been obtained. Similar phenomena are observable along the northern portion of the Central Belt from the Lammermuir Hills in the far north-east to the Portpatrick coast line (see pp. 198–9). Indeed, there seems no escape from the conclusion that, along the northern margin of the Central Belt, the Llandovery Rocks are partly represented by coarse sediments (grits, greywackes, and shales) which contain thin carbonaceous seams, yielding dwarfed representatives of Lower Birkhill graptolites.

The Tarannon Rocks of the Central Belt comprise, in descending order:

3. Grey, green, and red shales, brown flagstones, and yellow-crusted greywackes with occasional grits (Hawick Rocks).
2. Massive grits and greywackes with local bands of conglomerate, with grey, green, and red shales (Queensberry Grits).
1. Brown flagstones, green and grey shales and mudstones (Abbotsford Flags).

The dominant type of the Tarannon Rocks of the Central Belt consists of massive grits and greywackes (Zone 2), which are specially characteristic of the central and northern portions, while the members of the highest sub-division (Zone 3) are confined mainly to the southern margin of the area. The Abbotsford flags occur in the region between Melrose and Moffat.

Certain local bands of conglomerate occur in the Llandovery and Tarannon area (Pinstane Hill, Craigenputtock Hill), containing pebbles of volcanic and plutonic rocks (Arenig), radiolarian chert, grey shale, black shale with graptolites, greywacke, grit, quartzite, and mica-schist from the Highlands, &c. The largest pebbles, consisting of greywacke and granitoid igneous rocks, measure from eight to ten inches in diameter.

Fossils.—The distinctive fossils of the Birkhill Shales are graptolites which, both in genera and species, differ in a marked degree from the faunas of the underlying Hartfell and Glenkiln divisions. Though there is here a perfect passage from the Hartfell (Caradoc) Shales to the overlying Birkhill division (Lower Llandovery), a striking palæontological break nevertheless exists. The special features of this change in the facies of fossils are thus summarised by Professor Lapworth:

"Of the numerous genera of compound Graptoloidea which give such a varied character to the fauna of the Glenkiln Shales, and many of which have accompanied us in our upward progress into the typical beds of the Hartfell division, not one passes up into the Birkhill Shales. Here, on the other hand, the extraordinary prevalence of Monograptidæ upon every zone is in striking contrast to what occurs in the inferior division, where not the slightest trace of any form of this family has ever been detected.

"The two genera *Monograptus* and *Rastrites* swarm abundantly in all except the lowest zone of the Birkhill Shales,

and with the more sparingly distributed genera *Diplograptus*, *Climacograptus*, and *Retiolites* (together with a few scattered forms of Crustacea and Spongidæ) constitute the whole of the fossils of the group. Consequently, while there is no falling-off in respect of individuals or even species (many of the beds bearing favourable comparison with the most prolific horizons of the Hartfell Shales), yet, when contrasted with that afforded by the preceding divisions, the fauna of the Birkhill Shales is strangely monotonous throughout. No better proof could perhaps be adduced of our having clearly overstepped the limits of the great Llandeilo-Bala formation, where the Graptolithina attain their maximum, and that we are now almost on the threshold of those Upper Silurian Rocks where these strange old creatures disappear from our sight for ever."* (Plate XXVII.)

The zonal forms of the various divisions of the Birkhill Shales established by Professor Lapworth are given below in descending order:

Upper Division.	3. *Rastrites maximus* zone. 2. *Monograptus spinigerus* zone. 1. *Cephalograptus cometa* zone.
Lower Division.	3. *Monograptus gregarius* zone. 2. *Diplograptus vesiculosus* zone. 1. *Diplograptus acuminatus* zone.

The graptolites are associated with certain phyllocarid crustaceans which are represented by four genera, *Aptychopsis*, *Discinocaris*, *Peltocaris*, *Ceratiocaris*.

The study of the distribution of the graptolites in the Lower Llandovery Rocks of the Central Belt reveals certain peculiar features. It is evident that their distribution and to some extent their development were affected by the transport of coarse sediment from the northern land area, for not only do the higher sub-divisions of the Birkhill Shales with their characteristic forms one by one disappear, but even in those cases where the Moffat type is represented by thin carbonaceous seams in coarse sediments, there are only a few dwarfed representatives of the abundant Birkhill fauna. The forms seem to indicate arrested stages of development, as if the conditions had been unfavourable for their progress. The disappearance of most of the Birkhill forms and the stunted character of the survivors along the northern margin of the Central Belt make it difficult to fix with precision the northern boundary-line of the Llandovery Rocks of this region. These dwarfed forms include representatives of *Monograptus tenuis*, *Dimorphograptus*, *Diplograptus*, and a *Climacograptus* like *C. normalis*. (See pp. 200–1.)

The coarse sediments in the Tarannon Rocks of the Central Belt are almost wholly destitute of fossils. The forms which do occur are mainly graptolites, which are restricted to dark shales or thin carbonaceous seams. In these rocks we find some survivors of the Birkhill fauna, some, which are peculiar to

* Quart. Jour. Geol. Soc. Vol. XXXIV., p. 317.

the Tarannon series, and some which pass up into the Wenlock strata. The following may be quoted as examples of the first group, viz.: *Rastrites maximus*, *Monograptus Sedgwicki*, *M. leptotheca*, *M. spiralis*, *Petalograptus folium*, and *Climacograptus normalis*. But, in addition to these, we find species which now appear in the sequence for the first time, viz.: *Monograptus exiguus*, *M. crispus*, *M. vomerinus*, *M. galaensis*, *Retiolites geinitzianus*, and *Cyrtograptus*. Some of these forms, as will be shown in the sequel, pass upwards into the Wenlock formation; others, such as *Monograptus turriculatus*, *M. exiguus*, *M. crispus*, and *M. pandus*, are zonal forms, which, so far as our present knowledge goes, appear to be confined mainly if not exclusively to the Tarannon series.

In the Tarannon sub-division of the Stockdale Shales, in the Lake district, Messrs. Marr and Nicolson have established the following graptolite zones: (1) *Monograptus turriculatus*, overlain by (2) *M. crispus*. In the Central Belt of the Southern Uplands *M. turriculatus* is found in considerable abundance at certain localities in the shales immediately overlying the *Rastrites maximus* band, but it also occurs in higher beds intercalated in grits associated with *M. crispus*, *M. exiguus*, and *Retiolites geinitzianus*.

An interesting palæontological feature of these Tarannon Rocks is the abundance of tracks in red and green shales on certain horizons, as, for instance, *Crossopodia*, *Crossochorda*, *Dexolites*, *Myrianites*, *Nereites*, *Nemertites*. At present it is doubtful whether all these tracks are due to the burrowing of annelides; in some instances they may have been produced by univalve molluscs or even by crustaceans.

Some of the coarser grits and fine conglomerates in the eastern portion of the Central Belt yield fragments of corals, crinoids, and calcareous brachiopods.

Conditions of Deposition.—The lithological characters of the Birkhill Shales and their organic remains alike point to the continuance of oceanic conditions at the verge of sedimentation, in the central area, in Llandovery time. But stage by stage the coarse sediments from the northern land-surface invaded the floor of the Silurian sea, till eventually in Tarannon time they overspread the whole region. At intervals, however, during pauses in the transport of the coarse materials, fine dark mud was deposited, in which were entombed various species of graptolites.

The local conglomerates with pebbles of Highland schists, Arenig volcanic and plutonic rocks, greywackes, and shales point to local elevation and erosion of crystalline schists and Lower Silurian rocks outside the area of sedimentation.

NORTHERN BELT.

In this portion of the Southern Uplands no fossiliferous strata of Llandovery or Tarannon age have as yet been detected. It is not improbable, however, that there may be lenticular patches of these rocks in such a highly convoluted region, but, if so, they consist in all likelihood of barren sediments.

GIRVAN AREA.

The Llandovery and Tarannon Rocks of the Girvan area are represented by a thick mass of sediments, containing many highly fossiliferous zones, among which appear several graptolite-bearing bands yielding many of the zonal forms characteristic of these groups.

LLANDOVERY.

Rocks.—In the Girvan area there is a striking departure from the Llandovery phase of sedimentation represented by the Birkhill Shales in the Central Belt. The prominent zones of conglomerate with pebbles of Arenig igneous rocks, radiolarian chert, quartzite, mica-schist, quartz, and other ingredients; the shelly sandstones, the fossiliferous limestones, and calcareous grits and graptolite shales, plainly indicate the vast change in the character of sedimentation. The classification of the Girvan Llandovery Rocks established by Professor Lapworth may thus be briefly summarised in descending order:

Camregan Group, .	Grits, shales, limestone, and graptolite shales.
Saugh Hill Group, .	Conglomerates, grits, sandstones, shales, limestones, and graptolite shales of Woodland and Saugh Hill.
Mulloch Hill Group,	Conglomerates, shelly sandstones, and graptolite shales.

It is a remarkable fact that the members of the lowest or Mulloch Hill group, like the underlying Drummuck group, are confined to the Craighead inlier on the north side of the Girvan valley. Professor Lapworth has recorded a slight unconformability on the shore south of Girvan, where the Craigskelly conglomerate—the lowest sub-division of the Woodland beds (Saugh Hill group)—is believed to rest on the eroded edges of the Barren Flagstones (Caradoc). Whether or not this slight discordance may sufficiently account for the absence of these groups to the south of the Girvan valley, it is at least clear, from the recurrence of conglomerates with pebbles of Silurian rocks and Highland quartzite, that local elevation and erosion of the Silurian rocks must have taken place at no great distance to the north of the area of sedimentation.

Fossils.—The rich and varied fauna of the Llandovery Rocks of the Girvan area likewise affords strong proof of the great change in the sedimentation from that which prevails in the Central Belt. Though corals, trilobites, brachiopods, lamellibranchs, gasteropods, and cephalopods are largely represented, the group is also characterised by many graptolites.

The zonal Llandovery graptolites which have been recognised

by Professor Lapworth in the Girvan area are given here in descending order:

4. *Rastrites maximus.*
3. *Monograptus spinigerus.*
2. „ *gregarius.*
1. *Diplograptus acuminatus.*

The genus *Ptilograptus*, which occurs at the top of the Mulloch Hill sandstones, has not as yet been recorded from any other part of the Southern Uplands. The following genera of graptolites are represented in these Llandovery Rocks: *Climacograptus*, 1 species; *Diplograptus*, 2; *Dimorphograptus*, 1; *Petalograptus*, 1; *Monograptus*, 7; *Rastrites*, 1; *Retiolites*, 1; *Dictyonema*, 1.

Of the other great life-groups, the amorphozoa are represented by two genera, *Nidulites* and *Ischadites*. The corals number nine genera: *Aulacophyllum*, 1 species; *Favosites*, 4; *Heliolites*, 3; *Halysites*, 1; *Lindströmia*, 2; *Palæocyclus*, 1; *Petraia*, 2; *Pinnacopora*, 1; *Streptelasma*, 1. The echinoderms are represented by *Glyptocrinus*; the annelides by *Tentaculites*; and the polyzoa by *Ptilodictya*, 2 species; *Fenestella*, 1; *Retepora* 1.

Amongst the arthropods, the cirripedes include *Turrilepas* and the ostracods *Cythere*; while the trilobites number ten genera, viz.: *Calymene*, 1 species; *Cheirurus*, 1; *Encrinurus*, 1; *Illænus*, 3; *Lichas*, 2; *Phacops*, 3; *Acidaspis*, 1; *Proetus*, 1; *Bronteus*, 1; *Staurocephalus*, 1.

The brachiopods, which are extremely abundant in some of the zones, comprise fourteen genera, viz.: *Atrypa*, 3 species; *Crania*, 1; *Dinobulus*, 1; *Leptocœlia*, 1; *Leptæna*, 3; *Lingula*, 1; *Meristella*, 1; *Orbiculoidea*, 1; *Orthis*, 9; *Pentamerus*, 2; *Pholidops*, *Rhynchonella*, 4; *Stricklandinia*, 1; *Strophomena*, 7. The lamellibranchs number eight genera: *Ambonychia*, 1 species; *Avicula*, 1; *Cardiola*, 1; *Ctenodonta*, 1; *Orthonota*, 3; *Palæarca*, 2; *Pterinea*, 2; *Pleurorhynchus*, 1. The gasteropods are represented by eleven genera: *Bellerophon*, 7 species; *Cyrtolites*, *Euomphalus*, 2; *Holopea*, 1; *Holopella*, 2; *Macrocheilus*, 1; *Murchisonia*, 2; *Oriostoma*, 1; *Trochonema*, 1; *Trochus*, 1; *Platyceras*, 1. The cephalopods number six genera: *Cyrtoceras*, 1 species; *Gomphoceras*, 1; *Oncoceras*, 1; *Orthoceras*, 4; *Phragmoceras*, 1; *Trochoceras*, 1. Lastly, the pteropods so called number the following genera: *Conularia*, 2 species; *Hyolithes*, 1; *Pterotheca*, 1.

One of the distinctive palæontological features of these Llandovery Rocks of Girvan is the presence of two well-marked zones abundantly charged with Llandovery species of *Pentamerus*. The upper zone (Camregan Limestone and Grit), characterised by *Pentamerus oblongus*, *P. undatus*, *P. rotundus*, immediately underlies the *Rastrites maximus* band; the lower zone (Newlands Grits and Sandstones), containing *P. oblongus*, *P. undatus*, is interposed between the *Monograptus gregarius* shales (Glenshalloch) and the *Diplograptus acuminatus* mudstones (Glenwells). (See pp. 532–3).

TARANNON.

Rocks.—The Tarannon Rocks of the Girvan area include the greater portion of the Dailly series established by Professor Lapworth, and may be briefly summarised as follows:

Tarannon.	Drumyork Group.	Unfossiliferous flagstones and shales.
	Bargany Group.	Thick-bedded flagstones and shales with zones of shales.
	Penkill Group.	Grits, flagstones, and shales with graptolitic mudstones and shales.

It is worthy of note that the Tarannon Rocks of the Girvan area do not consist of such coarse sediments as those of the Central Belt; indeed the massive grits (Queensberry) of the latter region are sparingly represented at Girvan.

Fossils.—On several horizons graptolites of a distinct Tarannon facies appear; the zonal form of the Lower Penkill beds being *Monograptus exiguus*, and of the upper mudstones (Penkill group) *Cyrtograptus Grayæ*. Altogether five genera of graptolites occur in these rocks, viz.: *Monograptus, Diplograptus, Rastrites, Cyrtograptus, Retiolites.*

An analysis of the list of fossils obtained from the Tarannon Rocks of Girvan shows a remarkable diminution in the number of genera and species of the other life-groups compared with their development in the underlying Llandovery and Caradoc strata. For example, the corals are represented by two genera: *Heliolites, Palæocyclus*; the phyllopod crustaceans by *Discinocaris*; while only two genera of trilobites (*Encrinurus, Cheirurus*) have been recorded from this group.

There is a similar striking decrease in the brachiopods, which number five genera, viz.: *Atrypa, Discina, Orthis, Pentamerus, Strophomena.* The lamellibranchs include two genera, *Cardiola* and *Lunulicardium*; the gasteropods one genus, *Oriostoma*; and the cephalopods one genus, *Orthoceras.*

In the Girvan area of the Tarannon Rocks those peculiar tracks (*Crossopodia, Myrianites, Eione*) which are such a characteristic feature of similar strata in the Central Belt occur in red and green shales in the Penkill group. Finally, traces of plant remains have been obtained from this series of strata, but too imperfectly preserved for determination.

Conditions of Deposition during Llandovery and Tarannon time.—The sequence of Llandovery and Tarannon Rocks in the Girvan area, comprising conglomerates, shelly sandstones, limestones, graptolitic shales, &c., and their associated fossils, alike point to deposition either close to the shore, or in shallow water, or in comparatively clear water with the deposit of fine sediment. Though the land-surface lay to the north-west of the Silurian sea, there must have been local elevation and erosion both within and to the north of the area

of sedimentation. While the downward movement seems to have been in the ascendant, it is probable that the subsidence took place at intervals, the sea-floor being strewn with the prolific calcareous fauna, which gradually diminished in genera and species towards the close of the period.

WENLOCK AND LUDLOW.

SOUTHERN BELT.

Rocks.—The strata of Wenlock and Ludlow age extending along the southern margin of the Silurian tableland may be briefly described as follows, in descending order:

3. Green mudstones, with nodular calcareous bands.
2. Mudstones, shales, greywackes, grits, and conglomeratic bands with graptolite shales.
1. Flaggy grits and grey shale bands.

The members of the middle group form the greater portion of the Southern Belt of Wenlock and Ludlow Rocks, there being little variety in the lithological characters of the strata. The graptolite-bearing bands differ petrologically from the normal black shales of the Moffat series; they sometimes occur in zones fifty feet in breadth, and sometimes in thin leaf-like seams intercalated in the barren pale-coloured shales and flagstones.

Fossils.—The distinctive palæontological feature of the Wenlock and Ludlow Rocks of the Southern Belt is the constant recurrence due to folding of dark brown flaggy shales charged with graptolites, orthoceratites, phyllopod crustaceans, and sometimes eurypterids. Occasionally the pebbly grits contain fragments of brachiopods, corals, crinoids, and other organic remains.

The zonal graptolite of the Wenlock Rocks is *Cyrtograptus Murchisoni*—a species which here makes its appearance for the first time, and is characteristic of the lowest band of graptolite shale all across the belt from Burrow Head, in Wigtownshire, to Stobs Castle, near Hawick. The following genera of graptolites are found in these Wenlock beds: *Cyrtograptus* 2 species, *Dictyonema* 1, *Monograptus* 8, *Retiolites* 1—evidence which clearly points to the gradual extinction of this important group of organisms.

The sponges are represented by *Protospongia*; the corals by four genera, *Heliolites* 1 species, *Petraia* 2, *Stenopora*, *Syringopora*; the crinoids by *Glyptocrinus*; the annelides by *Cornulites*; the phyllopod crustaceans by three genera, *Aptychopsis* 3 species, *Ceratiocaris* 5, *Discinocaris* 1; the trilobites by two genera, *Phacops* and *Trinucleus*; and the eurypterids by two genera, *Eurypterus* and *Slimonia*. The brachiopods number seven genera, *Athyris* 1 species, *Atrypa* 1, *Leptæna* 2, *Lingula* 1, *Orthis* 6, *Rhynchonella* 2, *Strophomena* 1; the lamellibranchs seven genera, *Cardiola* 1 species, *Ctenodonta* 1, *Cucullella* 1, *Goniophora* 1, *Orthonota* 1, *Mytilus* 1,

Pterinea 1; the gasteropods two genera (*Bellerophon, Loxonema*); the pteropods two genera (*Hyolithes, Conularia*); while the cephalopods are represented by seven species of *Orthoceras*.

Conditions of Deposition.—The rapid alternation of graptolite shales with shales, flags, greywackes, and pebbly grits probably indicates minor oscillations of the sea-floor in the southern region during Wenlock and Ludlow time. The coarser sediments point to the transport seawards from the northern land-area of terrigenous materials during pauses in the downward movement, while the graptolitic shale represents the zone where only the finest sediment accumulated so slowly as to permit of its being coloured by the organic matter of the sea-floor and by the pelagic organisms which fell from the surface of the ocean.

BLAIR AND STRAITON AREA.

Rocks.—The strata which in the neighbourhood of Blair and Straiton, in Ayrshire, are regarded as of Wenlock age consist of, 1, flagstones and shales with graptolite-bearing seams (Blair and Knockgardner) overlain by (2) conglomerate, grits, and shales. They are the highest visible beds in the Silurian succession in that region.

Fossils.—Considerable difficulty has been felt in fixing the precise age of these beds in view of the palæontological evidence, but on the whole the balance of evidence seems to be in favour of grouping them with the Wenlock rather than with the Tarannon Rocks. The fossils are confined to certain thin carbonaceous seams and some calcareous grits.

The graptolites are represented by three genera, viz.: *Monograptus* (*M. riccartonensis, M. Flemingi, M. priodon, M. vomerinus, M. galaensis*), *Retiolites geinitzianus*, and *Cyrtograptus*. Two of these species, *M. riccartonensis* and *M. Flemingi*, are specially characteristic of the Wenlock Rocks of the Southern Belt. The entomostracans include three genera, *Beyrichia, Entomis*, and *Primitia*; the trilobites five genera (*Acidaspis, Calymene, Encrinurus, Phacops, Proetus*), and there is also a representative of *Eurypterus*. The brachiopods number seven genera (*Atrypa, Leptæna, Lingula, Orthis, Retzia, Siphonotreta, Spirifera*). Several of the species (*Atrypa reticularis, Orthis rustica, Retzia Barrandei, Spirifera sulcata*) are characteristic Wenlock forms. There are six genera of lamellibranchs (*Cardiola, Ctenodonta, Grammysia, Modiolopsis, Orthonota, Pterinea*): one of the species (*Cardiola fibrosa*) being a Wenlock form. The cephalopods are represented by three species of *Orthoceras* (*O. MacLareni, O. subundulatum, O. angulatum*), the first of these being a characteristic Ludlow and Wenlock form in the Pentland Hills.

LANARKSHIRE INLIERS.

Rocks.—Several miles to the north of the Silurian tableland, in Lanarkshire, strata of Wenlock and Ludlow age are exposed along anticlinal folds among Lower Old Red Sandstone and

Carboniferous rocks. These may be briefly summarised in descending order as follows:

Ludlow.	Upper Zones.	Sandy greywackes and shales passing downwards into shales and mudstones (*Trochus* beds) and flaggy shales (*Pterygotus* beds).
	Lower Zones.	Flagstones, greywackes, and brown shales (*Ceratiocaris* beds) passing downwards into olive shales and greywackes.
Wenlock, . .		Greywackes with partings of shale. (Base not seen.)

Compared with the prevalent petrological types of Silurian strata in the Southern Uplands, there is here a vast preponderance of sandy shales and mudstones.

Fossils.—Viewing the various "inliers" of Upper Silurian strata in Lanarkshire as one province, we find that several of the life-groups are poorly represented compared with their development in the Pentland Hills.

Only one or two fragments of graptolites (*Monograptus*) have been found in the Wenlock and Ludlow Rocks of Lanarkshire, and from one locality, near Carmichael Manse, south of Lanark. Only two genera of corals have been obtained (*Favosites asper*, *Lindströmia* sp.). Annelides are represented by two genera (*Spirorbis*, *Cornulites*), ostracods by *Beyrichia*, and trilobites by five genera (*Calymene* 1 species, *Encrinurus* 1, *Illœnus* 1, *Phacops* 1, *Proetus* 1).

The distinctive palæontological feature of these rocks is the abundance and excellent preservation of the phyllocarid crustaceans and eurypterids, which are more or less restricted to certain definite horizons. The former are represented by seven species of *Ceratiocaris*, and the latter by the following five genera: *Eurypterus* 3 species, *Pterygotus* 2 species and 2 varieties, *Slimonia* 1, *Stylonurus* 1, *Neolimulus* 1.

No less interesting are the remains of a scorpion (*Palœophonus*) and of a myriapod (*Archidesmus loganensis*) which have been obtained from these Upper Ludlow Rocks, proving the existence of air-breathers during this period in Scotland. From the description of *Palœophonus* by Mr. B. N. Peach it appears that this organism differed in no essential features from its living representatives, save that the walking limbs terminate each in a claw-like spike. To the narrow end of the trunk is articulated a long tail of five joints and a poison gland with a sting after the manner of recent scorpions.

The brachiopods number four genera (*Athyris*, *Orthis*, *Rhynchonella*, *Strophomena*); the lamellibranchs three genera (*Ctenodonta*, *Modiolopsis*, *Orthonota*); the gasteropods are represented by *Platyschisma* (*Trochus*) *helicites*; and the cephalopods by several species of *Orthoceras*. In the upper zones certain bands of sandy mudstone are crowded with specimens of *Platyschisma* (*Trochus*) *helicites* and *Modiolopsis complanatus*.

The recent discovery of fishes in the Ludlow rocks of Lanarkshire is of special importance. They have yielded two species of *Thelodus*, together with a fragment of another form too imperfect for determination.

PENTLAND HILLS.

Rocks.—The various inliers of Upper Silurian strata in the Pentland Hills, which are there completely surrounded by subdivisions of the Old Red Sandstone, are of great interest from the rich fauna furnished by the Wenlock and Ludlow Rocks. These strata may be briefly tabulated as follows:

Ludlow and Wenlock.

5. Green sandy and red shales underlain by brown sandy concretionary bands with *Platyschisma* (*Trochus*) *simulans*.
4. Concretionary brown sandstone with *Orthoceras MacLareni*.
3. Green and grey shales, mudstones, and sandy bands. Bands D and E of Henderson and Brown.
2. Massive sandstones and fossiliferous pebbly grits.
1. Thick group of grey, green, red, and purple shales, with occasional greywackes and grits containing the following subordinate zones in the middle of the series:
   - *c*. Buff-coloured mudstones (starfish band).
   - *b*. Flaggy micaceous greywackes (eurypterid band).
   - *a*. Thin limestone with encrinites and corals. (Base of series not seen.)

Fossils.—The distinctive palæontological feature of the Upper Silurian rocks of the Pentland Hills is the abundance of brachiopoda and of the various groups of mollusca. Indeed, since the original observations of the Geological Survey the researches of various local investigators, including Messrs. Henderson, Brown, Haswell, and others, have proved that brachiopods, lamellibranchs, and gasteropods must have swarmed in that portion of the Silurian sea, many forms being characteristic of Wenlock and others of Ludlow time.

Of considerable importance also is the occurrence of certain species of graptolites which, though few in number, are of zonal value in defining the Wenlock age of the strata at the North Esk reservoir, in the Gutterford Burn, and at Habbie's Howe. The following genera and species have been obtained from the various exposures of Wenlock Rocks in the Pentland Hills: *Monograptus colonus*, *M. Flemingi*, *M. priodon*, *M. vomerinus*, *Retiolites geinitzianus*, *Dictyonema assimile*, *D. regulare*, *D. retiforme*, *D.* (*Chondrites*) *verisimile*, *Cyrtograptus Murchisoni* (?).

The eurypterid band in the Wenlock series has yielded to the researches of Mr. Malcolm Laurie four new species of *Eurypterus*

(*E. conicus, E. cyclophthalmus, E. scoticus, E. minor*); three new species of *Stylonurus* (*S. macrophthalmus, S. ornatus, S. elegans*); and one new genus including three species, *Drepanopterus pentlandicus, D. bembicoides, D. lobatus*; together with a new species of *Slimonia*. In addition to these forms, *Slimonia acuminata* has been recorded from the Upper Ludlow Rocks of the North Esk section.

Of the other life-groups, sponges are represented by three genera (*Amphispongia* 1 species, *Plectoderma, Protospongia*); corals by eight genera (*Alveolites* 2 species, *Favosites* 3, *Heliolites* 2, *Lindströmia* 1, *Monticulipora* 2, *Petraia* 4, *Stenopora, Streptelasma*; the echinoderms by five genera (*Protaster, Perieschoechinus, Palæaster, Palasterina*. The polyzoa number four genera, *Ceriopora* 2 species, *Diastopora* 2, *Glauconome* 2, *Ptilodictya*; the annelids two genera, *Cornulites* and *Serpulites*; the cirripedes two genera, *Antifopsis* 1 species, *Turrilepas* 3 species; the phyllocarid crustaceans are represented by *Ceratiocaris*, and the trilobites by four genera, *Acidaspis* 1 species, *Calymene* 2, *Encrinurus* 2, *Phacops* 2.

Of the brachiopods there are eighteen genera: *Athyris* 1 species, *Atrypa* 2, *Chonetes* 2, *Crania* 1, *Cyrtia* 1, *Discina* 2, *Leptæna* 3, *Lingula* 4, *Meristella* 1, *Nucleospira* 2, *Orbiculoidea* 2, *Orthis* 9, *Pholidops* 1, *Rhynchonella* 4, *Skenedium* 1, *Spirifera* 1, *Strophomena* 9, *Whitfieldia* 1. The lamellibranchs are represented by twelve genera: *Ambonychia* 1 species, *Anodontopsis* 4, *Cardiola* 2, *Ctenodonta* 5, *Cucullella* 2, *Goniophora* 1, *Lunulicardium* 1, *Mytilus* 1, *Modiolopsis* 3, *Orthonota* 11, *Pterinea* 5, *Tellinomya* 1. The gasteropods number twelve genera: *Cyrtolites* 1 species, *Bellerophon* 4, *Cyclonema* 1, *Ecculiomphalus* 1, *Euomphalus* 5, *Holopea* 1, *Holopella* 3, *Loxonema* 1, *Platyceras* 2, *Platyschisma* 3, *Pleurotomaria* 2, *Tremanotus* 1. The pteropods (?) are represented by three genera, *Conularia, Hyolithes, Theca*; and the cephalopods by *Orthoceras* 9 species, *Lituites* 1, *Phragmoceras* 2.

Conditions of Deposition.—The strata of Wenlock and Ludlow age at Straiton, in Ayrshire, in Lanarkshire, and in the Pentland Hills imply a phase of sedimentation differing in some respects from that which obtains in similar rocks along the Southern Belt of the tableland. In the former case, while flaggy shales and sandy mudstones predominate, the marine fauna is richer and more varied; some of the bands yielding genera and species of different life-groups rivalling in number those of the prolific zones of Llandeilo, Caradoc, and Llandovery age in the Girvan area.

DOWNTONIAN.

INLIERS IN LANARKSHIRE AND PENTLAND HILLS.

Rocks.—The series of strata grouped under the term Downtownian has hitherto been regarded as of Lower Old Red Sandstone age, owing to the prevalence of red and yellow sandstones and shales which are the prominent feature of that formation. The recent discovery by the Geological Survey, in shales and mudstones intercalated in these sandstones, of a

marine fauna which in some respects is identical with that of the underlying Ludlow Rocks has led to a revision of the classification hitherto adopted. These passage beds are now viewed as forming the highest sub-division of the Upper Silurian rocks (see page 569). They may be briefly tabulated in descending order as follows:

Lower Old Red Sandstone, the basal bed being a coarse conglomerate or conglomeratic sandstone, with pebbles composed mainly of greywacke derived from the Southern Uplands.

Unconformability in the Pentland Hills and in Ayrshire, apparent conformability in Lanarkshire.

Downtonian.
4. Chocolate-coloured sandstones.
3. Conglomerate with quartzite pebbles derived from the Highlands.
2. Green and red mudstones with bands of greywacke and brown flaggy carbonaceous shales with fishes and eurypterids.
1. Red and yellow sandstones and mudstones, underlain in the Hagshaw Hills by a fine conglomerate of local occurrence, resting conformably on Upper Ludlow Rocks.

Fossils.—The organic remains, which are restricted to Zone 2 of the foregoing series of strata, consist of plants, ostracods, phyllocarid crustaceans, eurypterids, and fishes.

Among the fragments of plants obtained from this horizon, Mr. Kidston has identified *Pachytheca* and one specimen as belonging to the genus *Parka*, though of a different species from *P. decipiens*. The ostracods are represented by *Beyrichia*, a form which is common in the Upper Silurian rocks of the Southern Uplands; the phyllocarid crustaceans by *Ceratiocaris*. Most of the genera of eurypterids found in the Wenlock and Ludlow Rocks in Lanarkshire and the Pentland Hills, viz.: *Eurypterus*, *Pterygotus*, *Slimonia*, *Stylonurus*, have been obtained from the Downtonian fish-band (Zone 2 of above Table).

The most striking palæontological feature, however, is the remarkable assemblage of fishes procured from this horizon which are wonderfully complete when carefully extracted from the carbonaceous shales. Dr. Traquair has identified in the collection of the Geological Survey five genera of fishes, four of which are new, and seven new species. One genus (*Thelodus*) is common to the Upper Ludlow Rocks of Lanarkshire and Wales and to the Lower Old Red Sandstone of Forfarshire and Oban.

Conditions of Deposition.—The Downtonian strata indicate a marked change in the phases of sedimentation from those which obtained in Ludlow and Wenlock time in the South of Scotland. While it is true that the green mudstones, greywackes, and brown carbonaceous shales yielding fossils resemble lithologically Upper Silurian rocks, still the dominant feature of the series as a whole is red and yellow false-bedded sandstones. It seems just to infer that the Downtonian fish-band and the

associated mudstones and greywackes are marine deposits, for some of the eurypterids found in the latter strata are the associates of graptolites in the Wenlock Rocks of the Pentland Hills, and of brachiopods (*Lingula minima*) in the Ludlow Rocks of Lanarkshire. Moreover, the occurrence of the Polyzoon, *Glauconome*, together with *Spirorbis* and sponges, likewise points to the marine origin of some of the Downtonian strata. The red and yellow false-bedded sandstones, on the other hand, evidently herald those conditions which prevailed during Old Red Sandstone time, when the open sea gave place to brackish-water or inland lakes.

A further noteworthy feature is the abundance of pebbles of quartzite derived from the Highlands, in the conglomerate overlying the Downtonian fish-band—a fact which suggests that the Downtonian sediment may still have been derived chiefly from the Northern land area. The greywacke conglomerate at the base of the Lower Old Red Sandstone which extends from the Pentland Hills into Ayrshire points to the final elevation and denudation of the Silurian tableland; for in the Pentland Hills this conglomerate rests unconformably on the folded and eroded edges of the Wenlock, Ludlow, and Downtonian strata, and in Ayrshire on the Arenig lavas and sediments.

II. TECTONIC ARRANGEMENT OF THE STRATA.

We have now to describe briefly the present tectonic arrangement of the Silurian rocks as produced by the elevation of the tableland and modified by prolonged denudation.

Period of Elevation.—Towards the close of Downtonian time, and perhaps partly during earlier stages of that period, the Silurian strata were subjected to enormous lateral compression, whereby they were thrown into a series of folds, the axes of which run in a north-east and south-west direction, that is at right angles to the direction of pressure and parallel to the major axis of the tableland. By means of various denuding agencies this complex mass of folded strata was greatly worn down. Reference has been made in this chapter to the fact that local elevation and erosion of Silurian strata had taken place in Llandeilo, Caradoc, and Llandovery time, but this local ridging was insignificant compared with the elevation and erosion of the broad tableland of the Southern Uplands. Though the latter has been profoundly modified by denudation during subsequent geological periods, it is clear that this plane of erosion must have been in process of formation before the deposition of those portions of the Lower Old Red Sandstone which rest on the upturned and abraded edges of Silurian strata.

Isolation of Silurian Sub-formations by Denudation. — One striking result of the elevation and erosion of the tableland, aided by subsequent powerful faults, has been to separate various divisions of the system which were formerly continuous. For example, the Wenlock and Ludlow Rocks are restricted to the Southern Belt and to the north-west margin at Straiton, in

Ayrshire; while to the north of the great boundary fault which truncates the tableland they appear as inliers in Lanarkshire and in the Pentland Hills. Indeed, from the latter evidence it seems just to infer that Wenlock and Ludlow Rocks extend continuously from Ayrshire to the Lothians under younger Palæozoic strata. In like manner, the Tarannon Rocks form the greater portion of the Central Belt, being completely disconnected from strata of the same age in the Girvan area, while

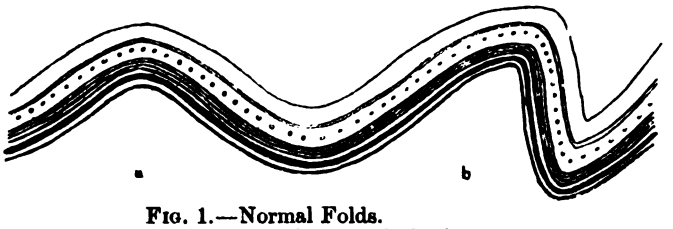


FIG. 1.—Normal Folds.
a. Symmetrical fold.
b. Asymmetrical fold.

in the Northern Belt the greatest development of Lower Silurian rocks is to be found. From these data it is evident that the tectonic centre of the tableland does not lie midway between its present north and south limits, nor does it coincide with the existing watershed of the region, but rather with the trend of the Northern Belt.

TYPES OF CURVATURE.

The dominant tectonic feature of the Silurian tableland is the extraordinary plication of the strata, of which striking proofs

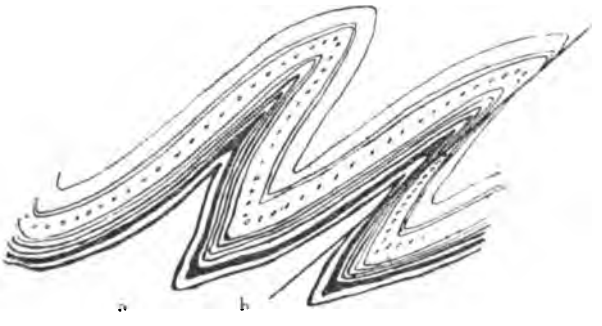


FIG. 2.—Isoclinal Folds.
a. Simple isocline.
b. Isocline with thrust fault.

can everywhere be obtained. Indeed, so complicated is the system of folding and so misleading is the apparent order of succession that all hope of solving the structural difficulties of the region might be abandoned, were it not for the key furnished by the vertical distribution of the graptolites. Various

types of curvature are illustrated in the Southern Uplands, which may be grouped generally in the following order:

Simple Folds.

1. Normal or symmetrical folds, where the strata dip away from a central axis at nearly equal angles. Usually they form sharp arches, the beds being highly inclined. A modification of this type sometimes occurs where the strata on one limb dip at gentle angles while those on the other side are highly inclined. (Fig. 1.)
2. Inverted folds, where the strata on both limbs of the flexure dip in one direction, form the dominant type in the Southern Uplands. Sometimes the axial planes of the inverted flexures are highly inclined; sometimes they form an angle of 15° to 30° with the horizon. Where this system of isoclinal folding prevails, and where the tops of the arches have been removed by denudation, the same zones may be repeated over miles of country, and thus give rise to deceptive estimates of their thickness. (Fig. 2a.)
3. Inverted folds with reversed faults, where the strata have snapped and the beds of the upper limb have been thrust for a short distance and made to overlie younger rocks. (Fig. 2b.)

Composite Folds.

4. Fan-shaped folds ("fan structure," Heim; anticlinorium, Dana; endocline, Lapworth; pseudo-synclines), where the primary fold is composed of a series of flexures, the axial planes of which are vertical in the centre and *dip towards* the central axis on the north-west and south-east sides, thus giving rise to a pseudo-synclinal arrangement of the strata. (Fig. 3a.)
5. Inverted fan-shaped folds (synclinorium, Dana; exocline, Lapworth; pseudo-anticlines), where the primary fold is composed of a series of flexures, the axial planes of which are vertical in the centre and *dip away* from the central axis on the north-west and south-east sides, thus producing a pseudo-anticlinal arrangement of the strata. (Fig. 3b.)

In the course of his researches into the complicated stratigraphy of the Southern Uplands, Professor Lapworth recognised all the foregoing types of curvature, and showed how they explained many of the structural anomalies of the region. His observations have been confirmed and extended by the subsequent investigations of the Geological Survey.

STRUCTURAL FEATURES OF THE SILURIAN BELTS.

Southern Belt.—Along the southern margin of the tableland the Wenlock and Ludlow Rocks are repeated by innumerable isoclinal folds, the axial planes of which generally dip in a south-east direction. Though of a limited thickness, their constant

repetition can be proved by means of the recurrence of the graptolite-shales. (See Map.)

Central Belt.—In the tract between Dumfries, Eskdalemuir, and Hawick, the strata (Hawick Rocks, Ardwell beds) form an inverted fan-shaped series of folds (Group 5 of foregoing Table). In the centre of the group of composite folds the axial planes are vertical, and on the north-west and south-east sides they dip away from the central axis, thus forming a pseudo-anticline.

The Moffat Shales appear at the surface along sharp anticlinal folds usually inverted, which may extend along the strike for

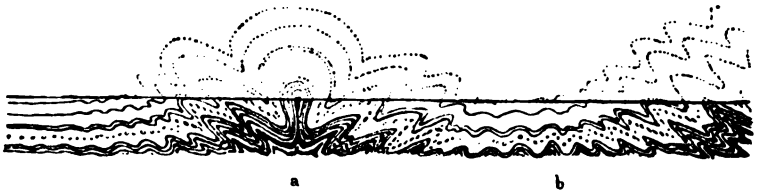


FIG. 3.—Composite Folds.
a. Fan structure (Heim), Anticlinorium (Dana.)
b. Synclinorium (Dana.)

several hundred yards or a few miles, the strata on either side being of Tarannon age. The total thickness of the black shale series (Upper Llandeilo, Caradoc, Llandovery) does not exceed 300 feet, while that of the Tarannon Rocks may be about 4000 feet. By constant reduplication these rock-groups cover a belt of country twenty-five miles wide. In the region between Moffat and Tweedsmuir and Beattock Summit—a distance of about ten miles—the prevalent dip of the axial planes of the isoclinal folds is towards the north-west.

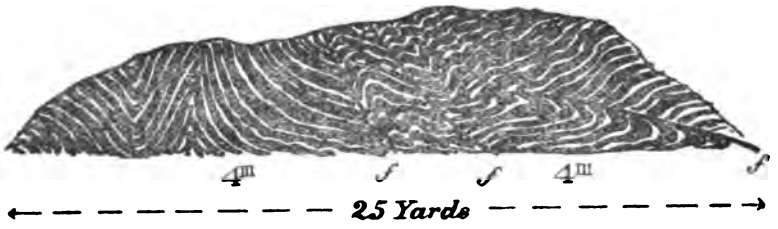


FIG. 4. Section of Birkhill Black Shales exposed in Garpol Burn, near Moffat, showing reduplication of strata by folding and faulting.

As might be expected, the Moffat Shales have been compressed into minute folds or wrinkles, which, in many instances, are accompanied by reversed faults. (Fig. 4.) Professor Lapworth proved the existence of the latter in the Selcoth Burn and other sections in the Moffat region. In the case of the inverted fold at Ettrickbridge-end, Selkirkshire, the south-eastern limb has been truncated by a reversed fault (Fig. 20), whereby the radiolarian cherts have been made to overlie the Tarannon

Isoclinal folds in green greywackes, mudstones, and shales, (Tappins series), Currarie Port, 3 miles south of Ballantrae.

flags and shales. But though reversed faults are not infrequent, there is here no evidence of great horizontal displacement as in the North-west Highlands. (See Map.)

Northern Belt.—In the tract between Nithsdale and Eddleston, in Peeblesshire, there is a remarkable development of Arenig volcanic rocks, radiolarian cherts, and Glenkiln-Hartfell shales which are constantly repeated by folding of the strata. Here the lavas appear in the cores of the anticlines, forming exposures, which measure sometimes only a few square yards in extent, and sometimes several hundred yards in length. Wherever a sufficiently low portion of the Silurian succession is laid bare by denudation the Arenig volcanic rocks invariably appear. A glance at the geological map of the Southern Uplands shows how, between Broughton and Leadburn, the great fault bounding the northern margin of the tableland truncates fold after fold of Lower Silurian strata with the Arenig lavas in the heart of the anticlines. Indeed, the radiolarian cherts and overlying black shales, which are sometimes so reduplicated as to form a continuous outcrop across the strike for about a mile, are here but a thin veneer concealing the underlying volcanic platform (see Figs. 59 and 60). While this volcanic series is exposed on numerous anticlines in the Northern Belt, it must have a wide extension throughout the Southern Uplands, for it has been followed from Girvan to Glenluce, from a point near Dalmellington to Trowdale, near Castle-Douglas, and again far to the north-east in the Moorfoot Hills. In short, it has been traced for a distance of about 100 miles from south-west to north-east over a part of the tableland sometimes thirty miles wide. If we assume that the Arenig volcanic series is continuous within these limits, then the area which it covers must be at least about 1500 square miles. (See Map.)

Evidence has recently been obtained in the course of the Geological Survey of the Eastern Highlands which probably points to an even greater extension of the Arenig volcanic rocks. Igneous rocks and radiolarian cherts have been recognised along the Highland border, by Mr. George Barrow between Cortachy, in Forfarshire, and Stonehaven; by Mr. C. T. Clough and Mr. J. R. Dakyns between Callander and Loch Lomond. The results of their work are thus briefly summarised by the Director-General: "For the purpose of our present inquiry two chief features of interest are presented by these rocks. They include a group of sedimentary strata among which occur bands of jasper or chert containing radiolaria, and one of their most conspicuous members is a series of volcanic rocks, consisting chiefly of dolerites and basalts, some of which have been crushed and cleaved, but in which vesicular structures can still occasionally be recognised.

"The striking resemblance of both the aqueous and igneous members of this marginal strip of rocks along the Highland border to the Arenig cherts and their accompanying lavas of the South of Scotland, the remarkable association of the same kind

of material in the same order of sequence, the occurrence of radiolaria in the siliceous bands in both regions, furnish strong presumptive evidence that a strip of Arenig Rocks has been wedged against the Highland schists. . . .

"The distance between the last Arenig volcanic outcrop in the Southern Uplands and the band of similar lavas along the margin of the Highlands is about 50 miles. If the volcanic ejections were continuous across the intervening tract, the total area over which the lavas and tuffs of the Arenig volcanoes were distributed must be increased by at least 6000 square miles in Scotland." *

The radiolarian cherts which invariably accompany the Arenig volcanic rocks have a greater visible extension in Scotland than that of the associated lavas, for they have been traced along the Highland border and across the Southern Uplands to Glenling, Wigtownshire, and south-eastwards to Ettrickbridge-end and Coldshiels Loch, near Melrose. The same zone has been recently recognised by the Geological Survey of Ireland among the Silurian rocks of that country, so that it must have extended far to the south-west of the present limits of the Scottish Silurian areas. For example, they occur at various localities in the eastern counties, where they are accompanied by black or dark shales, yielding Llandeilo or Arenig graptolites. Far to the west, at Tourmakeady, on Lough Mask, they have been detected with black shales of Lower Llandeilo or Arenig age; † while at Pomeroy they appear in association with volcanic rocks like the exposures along the eastern border of the Highlands of Scotland. They have been found still in great force in the Slieve Bernagh mountains, at the extreme south-western limit of the exposed Lower Silurian rocks of the British Isles.

In the central portion of the Northern Belt (Leadhills and Abington) there is a striking example of "fan structure," where in the centre of the primary fold the strata are folded on vertical axes while the axial planes dip inwards on the north-west and south-east sides, thus producing a pseudo-syncline. A glance at the horizontal sections of that region (see Sections 1, 2, 3 on Index Map) will show how strata not exceeding from 200 to 300 feet in thickness have been so compressed as to form continuous outcrops more than a mile across. Along the south-east side of the fan, the Lowther shales (Upper Caradoc) plunge underneath the Arenig cherts and Glenkiln-Hartfell black shales, with an inverted dip. In like manner, on the north side, along the margin of the tableland, the general dip of the strata is to the south-east. These inversions can be traced along the northern border to the Girvan area, where, in Penwhapple Glen, the Tarannon Rocks dip south-east underneath the Llandovery strata, and the latter appear to underlie Caradoc beds.

Inliers.—In the midst of the younger Palæozoic rocks interesting structural features occur in connection with the

* "Ancient Volcanoes of Great Britain." Vol. I., p. 201.
† Annual Report of the Geological Survey. 1897. Pages 48–49.

Silurian "inliers." For example, in the case of the Lesmahagow anticline in Lanarkshire, the Ludlow and Wenlock Rocks on the north limb of the fold dip away from the central axis at angles of 25°, while those on the south limb are more highly inclined and are abruptly truncated by a normal fault. This type of flexure is evidently the incipient stage of an inverted fold, for only a few miles to the south the Ludlow Rocks reappear in the Hagshaw Hills along an inverted arch which culminates in a reversed fault. (See Figs. 118 and 119.)

MODIFICATION OF OUTCROP BY PITCH OF FOLDS.

Among the highly convoluted rocks of the Silurian tableland curious structural features arise from the modification of outcrop by pitch of folds. The pitch of any anticlinal fold may be defined as the angle of inclination which the long axis of that arch makes with the horizon. Many of the inverted folds are merely elongated domes, which at their north-east and south-west limits pass underneath overlying strata. In the Northern Belt it sometimes happens that along the same line of strike, owing to the high pitch of the folds, strata are exposed in the valleys which are geologically higher than those on the adjoining hills. For example, in the Abington area of the Northern Belt the radiolarian cherts frequently form lofty ground, while in the same line of strike the overlying Glenkiln-Hartfell Shales appear in the valleys.

Conversely, it happens that along the same line of strike strata may be exposed on the low ground which are geologically lower than those on the adjoining heights. For instance, in the fine section of the Moffat series in Morroch Bay, south of Portpatrick (Fig. 98), the highly corrugated black shale series forms nearly the whole of the bay, while the adjoining lofty cliff is mainly composed of the overlying shales, flags, and greywackes.

SCHISTOSITY AND CLEAVAGE.

In consequence of the great lateral pressure to which the strata have been subjected, schistosity and cleavage have been superinduced on the rocks in certain areas. These structures are restricted to certain belts or zones where probably the mechanical strain producing interstitial movement has been most intense.

A prominent narrow belt of schistose rocks extends from New Galloway, north-east by Moniaive and the Dalveen Pass, to the watershed between Nether Howecleuch on the Eyan Water and Little Clyde. This belt lies at the southern edge of the great fan in the northern section of the tableland, where the axial planes are inclined to the north-west. Though microflaser structure has here been developed in the grits and greywackes, yet, from Mr. Teall's observations, it appears that "peripheral granulation, so common in the gneissose grits of the Southern Highlands, is entirely absent." It is worthy of note that the rocks showing extreme phases of contact alteration near the

granite of New Galloway, described by Miss Gardiner, occur within this belt of schistosity.

Again, within the Northern Belt, near the head of Menock Water, south of Wanlockhead, there is a small area where the Arenig igneous rocks, the cherts, and black shales have all been cleaved and where no fossils can be obtained to prove the horizon of the strata. Cleavage has also been superinduced in the Silurian strata on Ettrick Pen, on the north side of the inverted fan (pseudo-anticline) of the Hawick Rocks, and in the Hawick and Wenlock Rocks of Kirkcudbright and other localities along the southern margin of the tableland.

INTRUSIVE IGNEOUS ROCKS EARLIER THAN THE UPPER OLD RED SANDSTONE.

After their plication, cleavage, and denudation, but before the deposition of the Upper Old Red Sandstone, the Silurian strata of the Southern Uplands were invaded by various eruptive rocks which now form prominent geological features in the tableland. The largest of these plutonic masses (1, Criffel and Dalbeattie; 2, Cairnsmore of Fleet; 3, Loch Dee) occur in Galloway, where they cover many square miles of ground, but minor bosses appear at intervals across the chain from the headlands of Berwickshire to the Portpatrick coast-line. As examples of these smaller protrusions, reference may be made to the bosses at Kirkmaiden, near the Mull of Galloway; at Burnhead, north-west of Dalry; at Cairnsmore of Carsphairn, Knipe Hill, south of New Cumnock; Spango Water, north of Sanquhar; Cockburn Law and Priestlaw in the Lammermuir Hills, and the Dirrington Laws in Berwickshire. In addition to these, there are numerous dykes radiating from the large plutonic masses and likewise appearing in groups and isolated veins throughout the length and breadth of the tableland.

From the researches of Mr. Teall, which will be more fully given in Chapter XXVI., it appears that the numerous granitic protrusions throughout the Uplands all belong to one petrographical province. The main portion of the Criffel mass is a hornblende-granitite, containing basic inclusions of diorite, both being traversed by aplite veins of orthoclase and quartz. This dominant type is associated with quartz-diorites of the tonalite type. Both the hornblende-granitites and quartz-diorites sometimes contain a nearly colourless augite, thus giving rise to quartz-augite-diorites. Mr. Teall further shows that the Loch Dee mass is, petrographically, intermediate between that of Criffel and that of Cairnsmore of Fleet, comprising quartz-mica-diorites, hornblende-biotite-granites, and biotite-granites or granitites, the most acid rock being a granitite with microcline. He has also identified a group of rocks termed hyperites, representing the most basic facies of the granitic magma in the Loch Dee area. On the other hand, the dominant rock of the Cairnsmore of Fleet mass is granitite with microcline, which

forms only a subordinate part of the Loch Dee mass and has not yet been detected in the Criffel area.

While the granite occurs mainly in its usual massive form in the various protrusions, there is one region, on the eastern slopes of Criffel, where it has a marked foliated character. The evidence obtained in the field points to the conclusion that the foliation must have been superinduced on the massive granite after it had reached its present position and after the formation of the acid veins. For the hornblende-granitite, quartz-diorite, the basic inclusions, and the aplite, pegmatite, and quartz-veins have been foilated in one common direction. The general trend of the foliation in that region is north-east and south-west, in accordance with the general strike of the Silurian rocks, the dip of the foliation planes being in the same direction as that of the altered sediments. It is obvious, therefore, that these secondary structures have been developed in this portion of the granite mass of Criffel by dynamic action connected with earth-movements.

After the development of the foliation, the foliated granite was injected by a well-marked series of dykes of the same character and composition as some of those traversing the normal granite and the contact zone of Silurian sediments.

The numerous dykes radiating from the granite masses and occurring throughout the Silurian tableland comprise porphyrites, diorites of the camptonite type, mica-traps, and hyperites.

CONTACT METAMORPHISM.

Striking evidence is obtained of the contact alteration of the Silurian sediments by the granitic masses. The principal minerals of the altered strata, as given by Mr. Teall, are quartz, biotite, white mica, garnet, andalusite (including chiastolite), sillimanite, felspar, graphite, pyrite, rutile, tremolite, and malacolite. Owing to the variable nature of the sediments truncated by the granite masses, the aureoles of metamorphism cannot be divided into concentric zones, based on one type of rock. But in some instances it is possible to trace particular zones along the strike to their junction with the granite, and thereby follow the different stages in the alteration of the sediments. By this method Miss Gardiner has proved that the Silurian grits pass at the granite junction on Knocknairling Hill, New Galloway, into garnet-sillimanite-hornfels. The black shales also pass into graphite-schists with andalusite and chiastolite; the crypto-crystalline radiolarian chert into coarsely crystalline quartz-rock, the latter being accompanied by the development of minute biotite.

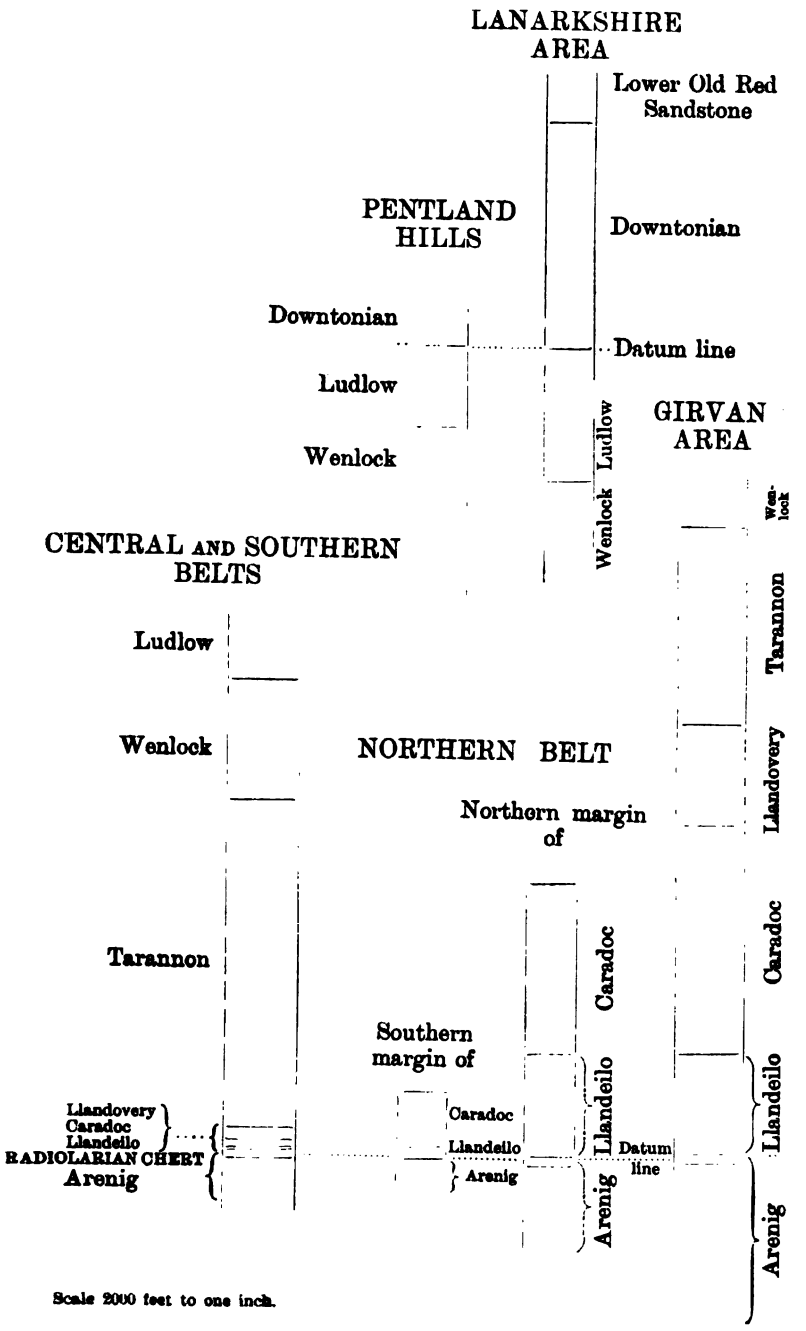
In like manner Mr. Teall has shown that the Arenig lavas, and in one instance near the edge of the Cairnsmore of Carsphairn mass, the intrusive ophitic dolerites, have been altered by the granitic protrusions, the minerals of the former being almost wholly of secondary origin.

It is highly probable that the granitic masses of the Southern Uplands and their apophyses may represent the plutonic rocks of the volcanic period of the Lower Old Red Sandstone. On the one hand they traverse sediments of Llandovery, Wenlock, and Ludlow age, and on the other hand they must be older than Upper Old Red Sandstone time, for strata of the latter period rest unconformably on Upper Silurian rocks pierced by apophyses of the granite. It is further evident (Explanation of Sheet 5, one-inch, p. 29) that the sediments under which the granite lay buried must have been removed and the igneous rocks exposed, before the formation of the beds of arkose, grit, and conglomerate which are such a conspicuous feature in the Lower Carboniferous series of the Colvend and Rerwick shores.

EXCAVATION OF THE VALLEY SYSTEM.

It is foreign to our present purpose to trace the development of the valley system of the Southern Uplands, which everywhere shows abundant proofs of sub-aerial erosion. But a brief reference is necessary to show that while the existing topography dates from Tertiary, and even post-Tertiary time, some of the valleys extend back to ancient geological periods when they were filled with younger Palæozoic deposits. Lauderdale may be taken as an example of those transverse hollows which traversed the tableland in Upper Old Red Sandstone time, when the conglomerates and sandstones were there laid down which are now being eroded by the Leader Water. Nithsdale and Loch Ryan represent pre-Carboniferous hollows, since, along the valley of the Nith and round the western shore of that loch, relics of Carboniferous strata are still to be found. And when we reflect that Annandale is floored with breccia and sandstone which are provisionally referred to the Permian period, and that similar deposits rest unconformably partly on Carboniferous and partly on Silurian strata in Nithsdale and Loch Ryan, successive phases in the evolution of the valley system are strikingly apparent. And yet, the main features of the existing valley system must be of much more recent date. From the relations of the Tertiary dykes which cross mountain and valley without interruption, and traverse alike Silurian and all younger Palæozoic rocks, it is obvious that the valleys must have been excavated since the eruption of these dykes. Thus we learn that only after prolonged denudation, during successive geological periods, the Southern Uplands have acquired their present topographical features.

TABLE showing relative thicknesses of Silurian Strata in the South of Scotland.



UPPER SILURIAN.

	Central and Southern Belts.	Northern Belt and Inliers of Lanarkshire and Pentland Hills.		Girvan Area.
		Lanarkshire:-	*Pentland Hills:—*	
Downtonian.		(2) Red sandstone, quartzite conglomerate, green and red mudstones (fish bands). Fishes, eurypterids, myriapods, plants, &c.	(2) Quartz conglomerate, sandstones, red and green mudstones. Fishes, polyzoa, &c. Thickness uncertain.	
		(1) Red and yellow sandstones with basal conglomerate. Total thickness — in Lesmahagow area, 2,700 feet; in Hagshaw Hills, 2,300 feet.	(1) Red sandstones with basal conglomerate. Thickness, 700 feet.	
	Kirkcudbright Shore and Riccarton:—	*Lanarkshire:—*	*Pentland Hills:-*	
Ludlow.	(2) Raeberry Castle Beds.—Mudstones with limestone nodules and Balmae grits. *Athyris, Atrypa, Orthoceras Etheridgei.* Thickness, 500-750 feet.	(2) Mudstones, sandstones, greywacke, and flaggy shales. *Platyschisma helicites, Orthoceras dimidiatum.* Phyllopods, eurypterids, scorpion, fishes. Thickness, 1,480 feet.	(2) Concretionary mudstone, sandstone, andshales. *Platyschisma simulans.* Thickness, 800 feet.	

Wenlock.	(1) Riccarton Beds.—Burrow Head, Kirkcudbright Shore, Dumfriesshire, Riccarton, and Cheviots.—Conglomerates, grits, greywackes, shales, and mudstones. *Cyrtograptus Murchisoni*, *Monograptus vomerinus*, *M. priodon*. Thickness, 1000-1500 feet.	(1) Greywacke and shales. Thickness, 1300 feet. Base not seen.	(1) Concretionary mudstones, grits, conglomerates, shales. Brachiopods, lamellibranchs, eurypterids, scorpions. *Cyrtograptus*, *Monograptus*. Thickness, 2200 feet. Base not seen.	Blair and Straiton Beds. Conglomerates, grits, flags, and shales. *Beyrichia Klædeni*, *Cardiola interrupta*, *Orthoceras Maclareni*. Thickness, 500 feet.
Tarannon.	**Hawick Rocks, Ardwell Beds.** Brown and grey greywackes and shales. *Protovirgularia*. **Queensberry Group.** Grieston Shales.—Grits and shales. *Cyrtograptus*, *Monograptus convolutus*, *M. priodon*, *Retiolites geinitzianus*. Buckholm Grits and Abbotsford Flags.—Massive conglomerates, flags, shales, and red mudstones *Monograptus exiguus*, *M. crismus*, *M. turriculatus*. Approximate maximum thickness, 3000-4000 feet.			Drumyork Flags, Bargany Group.—Flagstones and shales. *Cyrtograptus Grayi*, *Monograptus priodon*, &c. Thickness, 1100 feet. Penkill Group.—Grits, flagstones, and purple shales. *Monograptus exiguus*, *Crossopodia*, *Protovirgularia*, &c. Thickness, 1000 feet.
Llandovery.	**Birkhill Shale Series.** Upper. Thickness, 46 feet. { 3. *Rastrites maximus*-zone. 2. *Monograptus spinigerus*-zone. 1. *Cephalograptus cometa*-zone. Lower. Thickness, 52 feet. { 3. *Monograptus gregarius*-zone. 2. *Diplograptus vesiculosus*-zone. 1. *Diplograptus acuminatus*-zone.			Camregan Group.—Grits, limestones, and shales. *Rastrites maximus*, *Pentamerus*. Thickness, 200 feet. Saugh Hill Group.—Flagstones and shales. *Monograptus spinigerus*, *Rastrites peregrinus*. Thickness, 500 feet. Mulloch Hill Group.—Conglomerates, sandstones, and shales. *Diplograptus acuminatus*, *Meristella angustifrons*, *Atrypa*. Thickness, 350 feet.

	Central and Southern Belts.	Northern Belt.	Girvan Area.	
Caradoc.	**Hartfell Shale Series.** Upper or Barren Mudstone. Thickness about 60 feet. Mudstones with thin seams of black shales, thin tuffs, and agglomerate. 2. *Dicellograptus anceps*-zone. 1. *Dicellograptus complanatus*-zone. *Diplograptus socialis.* Black flaggy graptolite shales. Lower. Thickness about 40 feet. 3. *Pleurograptus linearis*-zone. 2. *Dicranograptus Clingani*-zone. 1. *Climacograptus Wilsoni*-zone. *Buthograptus laxus.*	**Lowther Shales** (Wrae, Glencotho, Winkston).—Grey and blue micaceous shales with conglomerates and limestones. Trilobites, brachiopods, cephalopods, &c. Volcanic rocks—felsitic lavas and tuffs (Wrae, Glencotho, Hamilton Hill, Winkston). Thickness about 800 feet. Black shales and flinty bands with Lower Hartfell graptolites (40 feet) passing laterally into greywackes and shales and calcareous conglomerates with Lower Caradoc fossils. Brachiopods, trilobites (Wallace's Cast, Duntercleugh, Kilbucho). Local unconformabilities in the districts of Channelkirk, Leadhills, Crawfordjohn, Sanquhar, and Shinnel Water. Volcanic rocks in lowest beds (Sanquhar district). Thickness about 1000 feet.	**Ardmillan Series.** Drummuck Group (Green Mudstones).—*Palæaster, Dicellograptus anceps, Trinucleus seticornis.* 400 feet. Barren Flagstone Group.—*Diplograptus truncatus, Nematolites Grayi.* Thickness, 800 feet. Whitehouse Group. — *Dicellograptus complanatus, Pleurograptus linearis, Diplograptus*, trilobites. Thickness, 300 feet. Ardwell Group. — Flagstones and shales. *Climacograptus caudatus, Dicranograptus ramosus.* Thickness, 1,200 feet. Balclatchie Group.—Mudstones, grits, and conglomerates. *Glossograptus Hincksi, Climacograptus bicornis.* Trilobites, brachiopods, &c., abundant. Thickness, 100 feet.	
	Glenkiln Shale Series. 4. Thin black shales underlying *Climacograptus Wilsoni*-zone. *Dicranograptus zic-zac, Climacograptus cælatus* var. *antiquus, C. peltifer, Lasiograptus bimucronatus.* Thickness about 2 feet.	Black shales with cherty bands (8 to 12 feet). *Didymograptus superstes, Cœnograptus, gracilis, Lasiograptus bimucronatus, Dicranograptus zic-zac, Dicellograptus divaricatus.*	Area S. of the Stinchar Valley. 4. Boulder conglomerate (Glenapp, Corsewall). Approximate thickness, 500 feet.	Area N. of the Stinchar Valley. **Barr Series.** 4. Benan conglomerate, about 500 feet thick.

Llandeilo.	3. Orange coloured mudstones, radiolarian cherts, and fine volcanic tuffs. Thickness at Dobb's Linn, 4 feet.	Black shales pass towards the north and west into grits, greywackes, and shales. Approximate thickness, 900-1200 feet.	3. Unfossiliferous mudstones and grits ("Tappins group"). Thickness about 500 feet.	3. Graptolitic mudstones. *Didymograptus superstes.* Thickness, 30 feet.
	2. Glenkiln Shales.—Black shales with cherty ribs. *Cœnograptus gracilis, Didymograptus superstes.* Thickness, 8-12 feet.	Volcanic rocks are associated with the passage beds between the Llandeilo and Caradoc divisions in the Sanquhar district.	2. Fossiliferous mudstones, *Didymograptus superstes, Cœnograptus, Dendrograptus,* 6 feet thick (Portandea).	2. Stinchar Limestone group, 60 feet thick.
	1. Radiolarian cherts, mudstones, and volcanic tuffs.	Radiolarian cherts and mudstones.	1. Mudstones and radiolarian cherts, passing conformably downwards into Arenig cherts and volcanic rocks.	1. Kirkland group, sandstones and conglomerates, *Orthis confinis* beds, 240 feet thick. Local unconformability.
Arenig.	Radiolarian cherts and mudstones with volcanic tuffs (Castle-Douglas district, &c.). Thickness about 150-200 feet at Trowdale, Castle-Douglas (Arenig and Lower Llandeilo cherts, &c.). Base not seen.	3. Radiolarian cherts. Thickness, 70 feet (Arenig and Lower Llandeilo cherts). 2. Mudstones with thin dark seams. *Obolella, Lingulella, Tetragraptus, Caryocaris Wrighti.* Thickness, 4 feet. 1. Volcanic series, comprising lavas, tuffs, agglomerates, and intrusive igneous rocks. Approximate thickness about 500 feet (Sanquhar). Base not seen.	Radiolarian cherts, mudstones, and volcanic tuffs. About 70 feet thick (Arenig and Lower Llandeilo cherts). Bennane Head black shales (*Tetragraptus bryonoides*) interleaved with volcanic agglomerate, 3-4 feet. Volcanic rocks, lavas, and tuffs, with fossiliferous intercalations yielding Middle Arenig graptolites. Approximate thickness, 1500 feet. Base not seen.	

CHAPTER IV.

Petrography of the Igneous Rocks in the Lower Silurian Formations of the Southern Uplands.

Lavas and tuffs of basic and intermediate composition occur in the neighbourhood of Ballantrae (Sheet 7) and in that of Sanquhar (Sheet 15). The petrographical description of the rocks is attended with considerable difficulty on account of the extensive alteration to which they have been subjected and the consequent unsatisfactory state of preservation of the specimens.

The rocks which undoubtedly occur as lavas in both localities are usually dark green, more rarely purple in colour. Two fairly well marked types may be recognised, but they are connected by more or less ill-defined transitional forms. The one type is a compact, dark green, non-porphyritic rock, often containing numerous small spherical amygdules, which usually measure about 2 or 3 mm. in diameter; the other is markedly porphyritic, containing large crystals of more or less altered plagioclase embedded in a dark green matrix.

These two types would be termed respectively diabase and diabase-porphyrite by German petrographers. Specimens of the latter type often bear a close resemblance to the well-known "porfido verde antiquo." (See Plate XVIII., Figs. 1 and 2; Plate XIX., Fig. 2.)

Both types, as well as the intermediate varieties with scattered and often inconspicuous phenocrysts of felspar, were in the first instance probably composed of plagioclase, augite, iron-ores, and a variable quantity of imperfectly crystallised interstitial matter. Augite may now be detected in some specimens, but it has often entirely disappeared. Only one generation of this mineral appears to have been present in the majority of the true lavas; but the tuffs contain large idiomorphic crystals similar in form and size to those which may be picked up on the slopes of Stromboli, and also rock-fragments in which similar crystals occur as phenocrysts.

When two generations of plagioclase occur, the phenocrysts are more basic than the constituents of the ground-mass. The former occur as thin or thick tables and sometimes as crystalline groups. They are often completely decomposed, and sometimes possess a green colour in consequence of the presence of chlorite. The felspars of the ground-mass of the "diabase-porphyrites" and of the non-porphyritic "diabases" occur either as microlites, or in forms giving the ordinary lath-shaped sections. The microlitic forms are especially characteristic of the lavas with "pillow-structure," in which porphyritic crystals are com-

paratively rare; the lath-shaped sections are, on the other hand, more characteristic of the rocks containing conspicuous phenocrysts of felspar.

Chlorite and carbonates are present in great abundance. They occur scattered through the rocks, and also in veins and as the infilling material of many of the amygdaloids.

The lavas with "pillow-structure" are of special interest, because rocks of the same general character, and possessing this remarkable structure, have been found associated with radiolarian cherts of different ages and in such widely separated localities as the Southern Uplands of Scotland, Cornwall, Saxony, and California.* A specimen from Gatelochside Burn, near New Cumnock, may be selected as a type of this class of lava. It was taken from the outer portion of one of the pillow-like masses, and is a greenish-grey, fine-grained rock containing small spherical vesicles, filled with calcite. Under the microscope the rock is seen to be composed of long slender microlites of felspar, chlorite, carbonates, and iron-ores. Granular augite was probably present, but, if so, it has entirely disappeared. There was doubtless also a small quantity of interstitial matter. The microlites of felspar are often curved, and sometimes arranged with their long axes more or less parallel to each orher, in consequence of differential movements in the magma before final consolidation. Flow-structure is not, however, a character of the rock as a whole. Those microlites which lie in the immediate neighbourhood of an amygdule show a tendency to arrange themselves tangentially with respect to the wall of the original cavity. All the microlites give approximately straight extinction and possess a refractive index closely agreeing with that of hard balsam. They are, therefore, oligoclase.

An analysis of this rock is given below, together with that of the "spheroidal basalt" from Point Bonita, near San Francisco, described by Mr. Leslie Ransome.† It is interesting to note that the latter rock is also associated with radiolarian cherts

	I.	II.
SiO_2	46·4	49·45
TiO_2	·24	2·23
Al_2O_3	20·4	17·58
Fe_2O_3	6·9	3·41
FeO		3·41
CaO	7·7	7·20
MgO	3·5	4·05
Na_2O	6·93	5·85
K_2O	·54	1·57
CO_2	5·8	...
Loss on ignition (less CO_2),	1·1	Total loss, 4·34
	99·51	99·07

* On Greenstones associated with Radiolarian Cherts. By J. J. H. Teall. Roy. Geo., Soc., Cornwall. 1894. Page 3.

† The Eruptive Rocks of Point Bonita. University of California. Bull. Depart. Geol. Vol. I., p. 106.

I. Amygdaloidal "diabase," Gatelochside Burn, near New Cumnock. Specimen taken from outer portion of one of the pillow-like masses.

II. Spheroidal basalt from exterior portion of a large spheroid, Point Bonita, California.

The rock from Point Bonita bears a very close resemblance to that from New Cumnock both as regards macroscopic and microscopic characters. Both rocks show the same "pillow-structure," both contain spherical amygdules of about the same size, in both the amygdules are more common in the outer portions than in the centres of the pillow-like masses, both are associated with radiolarian cherts, and both have the same mineralogical composition and microscopic structures. Under these circumstances it is interesting to note that they possess marked chemical affinities. The special feature is the high percentage of alkalies, 7·4 in both rocks, as compared with the low percentage of silica.

Other specimens of the pillow-lavas, both from the Ballantrae and Sanquhar areas, agree in general characters with the one selected as typical of the group. The principal differences arise from the occasional presence of micro-porphyritic felspars and the more pronounced development in some rocks of interstitial matter containing grains or rods of iron-ore and extremely minute felspar-microlites. In some cases the amygdaloidal cavities have been wholly or partially filled with this interstitial matter. In one case tuffaceous fragments were observed in a section prepared from a specimen taken from the interior of one of the "pillows." This points to the conclusion that the pillow-like masses, in rolling over, incorporated scoriaceous fragments which either fell upon the stream or were formed by the breaking up of portions of the stream itself.

The pillow-lavas above described present many points of resemblance to the variolitic diabases of Mont Genèvre. In speaking of these rocks, Messrs. Cole and Gregory* say: "The "most striking character of the compacter series is a tendency "to spheroidal jointing. Sometimes, as among the crags "forming the east side of the Chenaillet valley, south of Mt. La "Plane, the spheroids appear piled regularly one above the "other, forming walls, as it were, which are divided by con-"spicuous vertical joints; but the structure is more commonly "irregular, the masses resembling pillows or soft cushions "pressed upon and against one another, each cliff face thus "exhibiting a number of swelling surfaces and curving lines "of junction. Examined more closely, small vesicles are seen "in these rude spheroids, especially toward the margins; and "in some places, as on the east of Mt. La Plane, the whole rock "becomes vesicular and slaggy. The surfaces of the masses are "covered by a crust of variolite, from 1 to 7 or 8 centim. thick."

* The Variolitic Rocks of Mont Genèvre. Quart. Jour. Geol. Soc. Vol. XLVI. (1890), p. 311).

Variolitic rocks have not as yet been found in the Ballantrae and Sanquhar areas, but it is clear from this quotation that the conditions which led to their formation at Mt. Genèvre have been closely approximated to in those regions. It is interesting to note that at Ballantrae, in Cornwall, and at Mt. Genèvre, diabasic lavas with pillow-structure occur in the immediate neighbourhood of gabbro and serpentine, and that in all three localities some difficulty is experienced in determining the precise relations of the plutonic and volcanic rocks.

The rocks of the "diabase-porphyrite" type do not require detailed description. (Plate XIX., Fig. 2.) The large felspars, which are always so much altered as to make identification difficult or impossible, are sometimes embedded in a ground-mass similar to that of the rock above described, and sometimes in one which is more coarsely crystalline. In the latter case augite is often preserved, the felspars are lath-shaped, not microlitic, and the iron-ores are represented by plates of ilmenite.

The pyroclastic rocks which are associated with the lavas, both in the Ballantrae and Sanquhar areas, are composed of crystals, crystal-fragments, and lapilli derived partly from lavas similar to those above described, and partly from rocks of a different character which have not been observed in the form of lavas.

The common type of lava does not contain phenocrysts of augite and hornblende, but the tuffs of Bail Hill, near Sanquhar, have been largely formed by the breaking up of a magma in which crystals of these minerals, often measuring more than $\frac{1}{4}$-inch in diameter, had separated out.

These augitic and hornblendic tuffs are dark green, often almost black in colour, and it is frequently difficult to recognise their tuffaceous character in the hand specimen. The black crystals of augite sometimes project from the freshly-broken surface. Their angles are often quite sharp, and the forms observable are those of the clinopinacoid (010), orthopinacoid (100), prism (110), and the positive hemipyramid ($11\bar{1}$). Under the microscope the sections of this mineral are yellow or yellowish-green, and a slight pleochroism may often be detected. Inclusions of magnetite are common.

The hornblende, which is sometimes found in association with the augite and sometimes by itself, occurs under similar conditions. The crystals are bounded by the clinopinacoids, the faces of the prism, and by the terminal faces which probably represent a hemipyramid and the basal plane. Under the microscope this mineral is brown or greenish-brown; but the colour is not so strong as in ordinary basaltic hornblende. Sometimes the outer portion of an individual is more deeply coloured than the interior, thus giving rise to a kind of zonal structure. Twinning of the common types may occasionally be seen both in augite and hornblende. Associated with these minerals we find also numerous crystals and crystal-fragments of altered plagioclase similar to that occurring in the lavas of the "diabase-porphyrite" type.

Amongst the rock-fragments which occur in the tuffs are lavas of the "diabase" and "diabase-porphyrite" type, and also rocks containing phenocrysts of augite and hornblende in addition to those of plagioclase felspar. The ground-mass of these latter rocks contains microlites of felspar, grains of iron-ore, and in some cases minute prisms of hornblende or grains of augite. It is often, however, too much altered for precise description. A careful study of the rock-fragments in the tuffs and agglomerates of Bail Hill makes it highly probable that augite-andesites (augite-porphyrites of many authors), hornblende-andesites, and augite-hornblende-andesites contributed to the formation of these rocks.

The only other locality in Great Britain where rocks like those of Bail Hill are known to occur is at Rhobell-Fawr, in North Wales. This locality has been described by the Geological Survey* and by Professor Cole†, and the petrographical descriptions of the latter author leave no doubt that the phenomena are substantially identical in both areas. Similar rocks occur near Predazzo, in the South Tyrol, where they have been described as tuffs of augite-porphyrite or porphyry.

Some interesting volcanic rocks of Bala age from Sheet 24 have recently been examined. Amongst these are soda-felsites or keratophyres and perlitic felsites. The soda-felsites occur in Wrae Quarry, near Broughton; at Hamilton Hill, 1¾ mile north-west of Peebles; and in Glencotho Quarry, Holms Water, near Broughton; perlitic felsites are found at Winkston Hill, 2 miles north of Peebles.

The rock of Hamilton Hill may be taken as a type of the soda-felsites. (Plate XXI., Fig. 1.) It is composed of small phenocrysts (3 or 4 mm.) of felspar in a compact dark greenish matrix. The phenocrysts usually give rectangular or rhombic sections, the former being three or four times longer in one direction than the other. They occur also occasionally in the form of crystalline groups. The determination of these phenocrysts is attended with considerable difficulty. They are certainly in all cases alkali-felspar, but they may be in part an acid plagioclase, and in part either orthoclase or more probably anorthoclase. The ground-mass is an aggregate of microlitic felspars, having ill-defined boundaries. Like the keratophyres and bostonites the rock is almost entirely composed of alkali-felspars. Ferro-magnesian minerals formed only a very small proportion of the original rock. They are represented now by extremely minute scales of chlorite, which are associated with the microlitic felspars of the ground-mass.

The rock was analysed with the following result:

Silica	64·38
Alumina	16·98
Ferric oxide	4·04
Carry forward . . .	85·40

* Mem. Geol. Survey of Great Britain. Vol. III. (2nd Edit.), p. 58.
† The Rocks of the Volcano of Rhobell-Fawr. Geol. Mag. 1893, p. 337.

Brought forward . . .	85·40
Lime	1·08
Magnesia	·28
Soda	7·57
Potash	4·30
Loss on ignition	1·64
	100·27

All the other varieties of soda-felsite resemble the one above described in the character of the phenocrysts, but they differ somewhat in the structure of the ground-mass. This is sometimes cryptocrystalline rather than microlitic, and not unfrequently it shows a spotted appearance under the microscope when viewed with ordinary light.

The perlitic felsites of Winkston Hill (Plate XXI., Fig. 2) are compact, dark reddish, mottled rocks. Under crossed nicols, they are cryptocrystalline with frequent traces of very minute microlites. The perlitic structure is very perfectly developed. Small irregular patches of carbonate occur, apparently replacing portions of the original felsite, and the perlitic cracks traverse these patches. Ferrite is scattered through the rock, and occurs also in the perlitic cracks. It is probable that these perlitic rocks are soda-felsites, but the point has not been definitely settled by analysis.

The petrological characters of the serpentines and gabbros of the Ayrshire coast have been well described by Professor Bonney.* These rocks bear the closest possible resemblance to the corresponding rocks of the Lizard district in Cornwall. The serpentine of Balhamie Hill, near Colmonell, is composed of glittering crystals of enstatite or bastite in a black compact matrix, and is substantially identical with the black serpentine of Cadgwith. As stated by Professor Bonney, it is an altered olivine-enstatite rock. The following analysis of this rock, made by Mr. Haughton, is quoted from Professor Bonney's paper:

Silica	38·29
Alumina	3·95
Ferric oxide	2·53
Ferrous oxide	4·04
Lime	0·57
Magnesia	35·55
Manganese oxide	tr.
Nickel oxide	·15
Iron sulphide	tr.
Water	14·08
	99·16

* On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast. Quart. Jour. Geol. Soc. Vol. XXXIV. (1878). pp. 769–785.

The Survey Collection includes several specimens of serpentines derived from saxonites (olivine-enstatite rocks) in addition to those from Balhamie Hill. In all cases the microscopic structure is perfectly characteristic. Large individuals of enstatite or bastite lie in a matrix of serpentine showing the well-known "mesh-structure." In addition to serpentines derived from saxonites there is one derived from dunite, in which picotite occurs as an important accessory, and others about the origin of which it is impossible to speak with confidence. There is no doubt, however, that all have been derived from igneous rocks belonging to the peridotite family. The chrome-spinelle (picotite) which is often present as an accessory constituent has occasionally segregated in masses of considerable size, and the collection includes a specimen measuring 2¼in. by 2in. by 1½in., almost entirely composed of this mineral. Closely allied to the serpentine in composition is a peculiar rock from Lochton, near Girvan, mainly composed of irregular grains of a colourless monoclinic pyroxene, but which contains also irregular patches of a soft brown substance (? bastite). This rock may be termed a pyroxenite.

The gabbros vary considerably in composition and structure. The ferro-magnesian minerals include augite, diallage, uralitic or fibrous hornblende, and a compact brown hornblende which has many of the characters of an original constituent. In one or two specimens the compact brown hornblende appears to be the only ferro-magnesian mineral present, so that these rocks are diorites rather than gabbros; but as they are closely linked on to the more normal gabbros by the occurrence of transitional forms, and as they resemble the gabbros in general appearance and in structure, it has not been thought desirable to separate them under a distinct name.

The felspars of the gabbros are rarely present in their original condition. They are usually represented by white or cream-coloured, compact, hard, saussuritic aggregates which do not admit of any very precise description. It is now well known that many so-called saussurites are aggregates of zoisite or epidote and albite or some allied felspar, but this is not the case with the aggregates in question. Not unfrequently they are largely composed of a pale brown isotropic substance occurring in large irregular patches or in small grains. This substance resembles garnet in many of its characters, but as crystalline form is absent it is impossible to speak with confidence as to the identity of the mineral.

Another mineral which enters into the composition of these dense white aggregates, and which is certainly an alteration product after felspar, is colourless, strongly double-refractive, biaxial, and apparently positive. This mineral occurs in grains which mutually interfere with each other and never shows any definite form or cleavages from which its crystalline system can be inferred.

In specimens of gabbro from Burnfoot, one mile south of

Lendalfoot, the felspar has been replaced by a soft aluminous serpentine (pseudophite) similar to that occurring in a gabbro-dyke traversing normal serpentine near Kynance, in Cornwall.

The hand specimens of the rocks vary considerably in structure. Some are very coarse and formed of black and white patches measuring an inch or more across, others are of medium grain; some are massive, others show a marked flaser-structure, and a few may be described as banded or even laminated. Under the microscope the massive varieties are granitic in structure, the banded varieties are granulitic, while the flaser-gabbros show a combination of granitic and granulitic structures. The foliation is evidently the result of interstitial movement either during or subsequent to consolidation, and the granulitic structure is a consequence of this movement.

The other intrusive rocks of the district may be grouped as dolerites (ophitic)—Plate XXII., Fig. 2, and Plate XXIV., Fig. 1,—hornblende-dolerites, epidiorites (altered dolerites), diorites, quartz-diorites, and granitites. Hornblende-schists, which are so common at the Lizard, appear to be rare. The Survey Collection includes, however, specimens of this rock from the north face of Carleton Hill and from the hill-slope one-third of a mile south-west of Loch Lochton.

CHAPTER V.

Detailed Description of the Silurian Region of the Southern Uplands.

I. THE CENTRAL BELT.

TYPICAL SECTIONS OF THE MOFFAT BLACK SHALE SERIES.

THE typical sections of the Moffat series in Dobb's Linn and Craigmichan Scaurs selected by Professor Lapworth, and described by him in his paper on "The Moffat Series," illustrate the lithological and palæontological sub-divisions of the different groups. The exposures of the two higher groups (Birkhill and Hartfell) in Dobb's Linn are complete, only a small development of Glenkiln Shales being there visible. This hiatus is, however, partly supplied by the section in Craigmichan Scaurs, where the members of the Glenkiln group are well displayed. Even there, however, the base of the latter group is not seen, their relations to the Arenig volcanic rocks not being clearly defined within the Moffat region.

Dobb's Linn, Moffatdale (Fig. 5).

This famous section occurs at the head of Moffatdale; it is about ten miles from Moffat, five miles from St. Mary's Loch, and about half a mile from Birkhill Cottage on the watershed between Moffat valley and one of the tributaries of the Yarrow. At this spot, three streams unite to form the Moffat Water, two of them draining the eastern side of the valley, while the third (Dobb's Linn), flowing down the western slope, has cut a deep gorge through the black shale series.

Ascending the latter stream, which there runs parallel to the strike of the Silurian rocks, the observer finds a magnificent exposure of the black shale series rising along an anticlinal fold in the Tarannon greywackes and shales. About 350 yards up the stream it is joined by a small tributary, draining the high grounds to the west, which forms a conspicuous lateral gorge, traversing the black shales more or less at right angles to their strike. At the head of the lateral gorge there is a fine waterfall, where the stream leaps over the Tarannon greywackes and shales on to the softer beds of the Upper Birkhill group. Admirable exposures, too, occur in the corrie north of the lateral gorge, and particularly in the Main Cliff to the south of that gorge. On the 6-inch map, the name "Dobb's Linn" is applied to the main stream, though originally

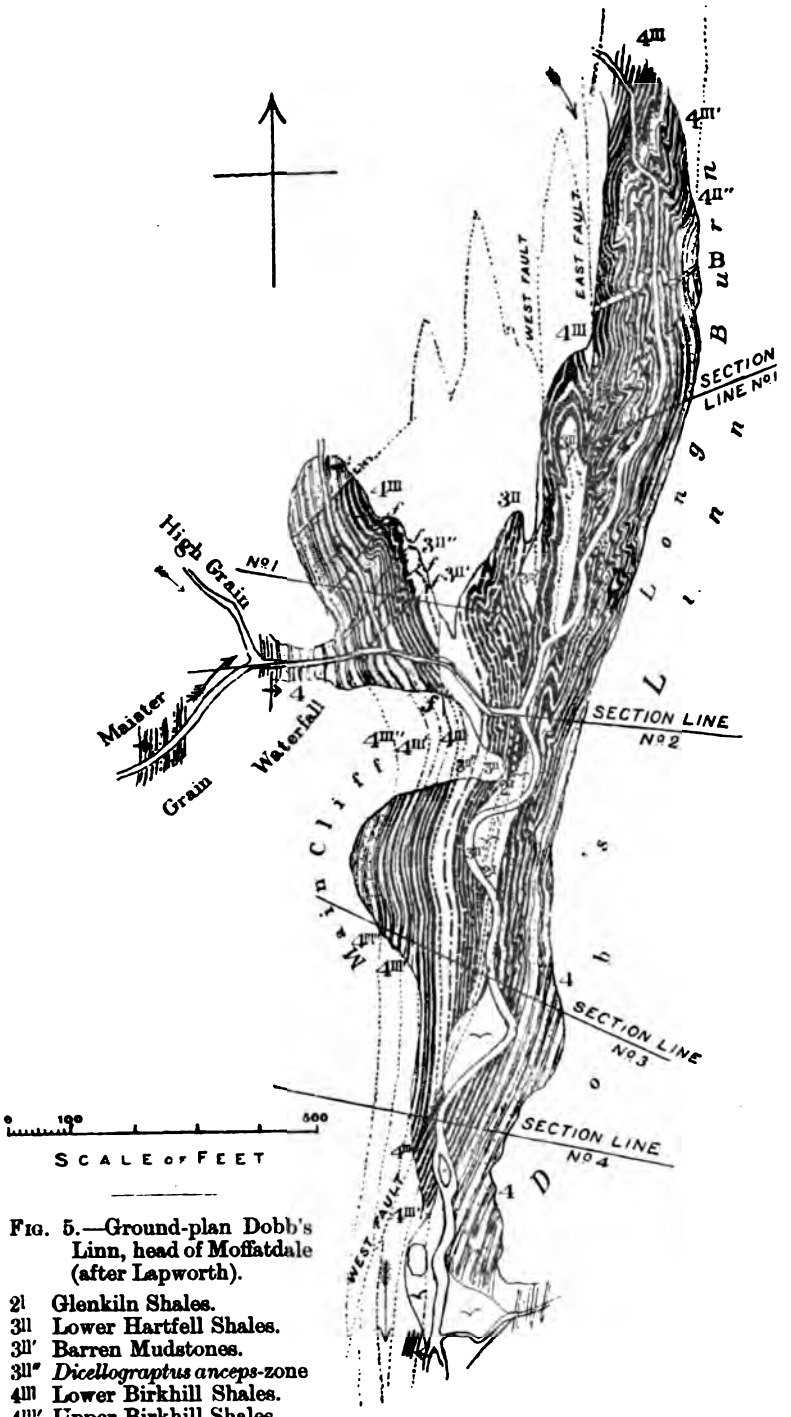


FIG. 5.—Ground-plan Dobb's Linn, head of Moffatdale (after Lapworth).

2l Glenkiln Shales.
3II Lower Hartfell Shales.
3II' Barren Mudstones.
3II'' *Dicellograptus anceps*-zone
4III Lower Birkhill Shales.
4III' Upper Birkhill Shales.
4III'' *Rastrites maximus*-zone.
~ Recent alluvium.

restricted to the waterfall at the head of the lateral gorge. The upper portion of the main stream is termed the Long Burn.

The members of the Moffat series, in the Dobb's Linn section, as Professor Lapworth has shown, are not arranged in a normal anticline. For example, towards the southern limit of the arch, the black shales and the Tarannon greywackes dip uniformly to the north of west as if there were an ascending sequence from east to west (Fig. 6, Sec. 4 in ground-plan). Again, on the western limit of the fold, the Tarannon greywackes and shales at the waterfall dip east at high angles, below the Birkhill beds that are exposed in the lateral gorge, thus indicating an apparent upward succession from west to east (Fig. 7, Sec. 2 in ground-plan). It is obvious, therefore, that the strata along these two lines of section are partly inverted, and hence no reliance can be placed on mere superposition. Indeed, it is only by following the outcrops of the various sub-divisions of the series and determining their horizons by means of the graptolites that their physical relations can be satisfactorily established.

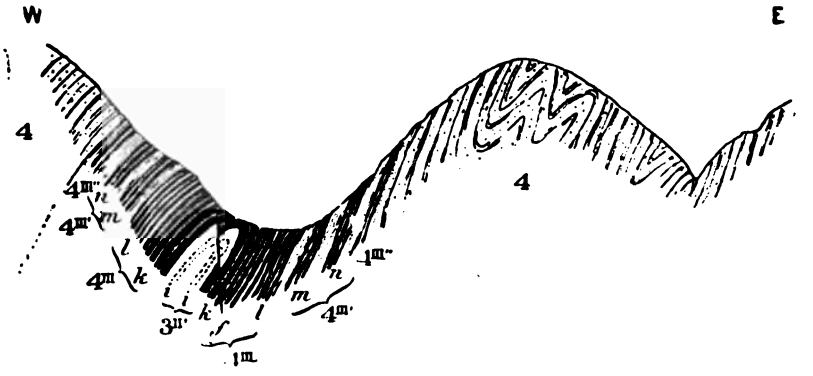


FIG. 6.—Section in Dobb's Linn (No. 4 of Fig. 5).

3II' Barren Mudstones—i. *D. anceps*-zone. 4III L. Birkhill—k. *D. vesiculosus* and *D. acuminatus* zones—l. *M. gregarius*-zone. 4III' U. Birkhill—m. *D. cometa*-zone—n. *M. spinigerus*-zone. 4III'' *R. maximus*-zone. 4 Tarannon.

It is further observable that a prominent fault runs along the crest of the arch in a N.N.E. direction (Fig. 5, West Fault), forming an important structural line. For at the base of the Main Cliff, near the southern termination of the fold, it brings the Glenkiln black shales into contact with the Barren Mudstones (Fig. 8, Sec. 3 in Fig. 5), while towards the north-east it places the Hartfell black shales in conjunction with the Lower Birkhill Shales (Fig. 9, Sec. 1 in Fig. 5). A second dislocation (East Fault in ground plan, Fig. 5) runs for a short distance along the west slope of the Long Burn. Another fault, of minor importance, however, occurs in the lateral gorge between the Barren Mudstones and Lower Birkhill Shales. Notwithstanding these dislocations the zones established by Professor Lapworth can

be readily identified, and the graptolites can, in most cases, be obtained in excellent preservation.

Taking, first, the section in the lateral gorge, showing the strata in inverted order (Fig. 7, Sec. 2 in Fig. 5), we find the flags and green shales at the waterfall dipping at angles from 70°–80° below the grey shales, with four thin black seams belonging to the zone of *Rastrites maximus* (Carr). The latter form the highest fossiliferous zones of the Upper Birkhill beds in this section. The following fossils have there been obtained from this horizon (Fig. 7, $4^{III''}$):

Monograptus Sedgwicki (Portl.)
,, *turriculatus* (Barr.)
,, *Hisingeri* (Carr.)
,, *attenuatus* (Hopk.)

Rastrites maximus (Carr.)
Petalograptus folium (His.)
Peltocaris aptychoides (Salt.)

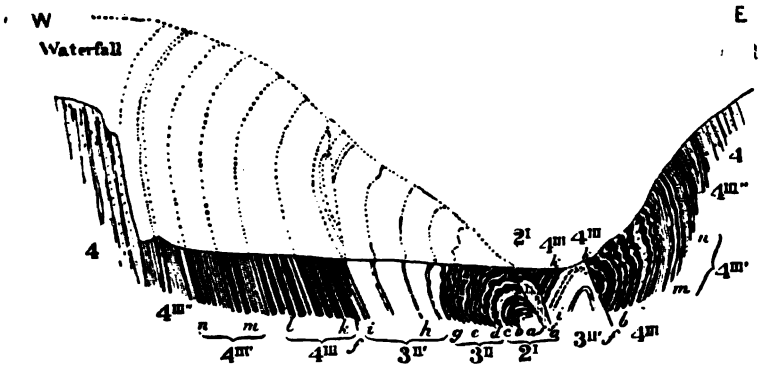


FIG. 7.—Section in lateral gorge, Dobb's Linn (No. 2 of Fig. 5).

2^{I} Glenkiln Shales—a. radiolarian chert, b. *C. gracilis*-zone, c. mudstone and chert. 3^{II} Lower Hartfell Shales—d. *C. Wilsoni*-zone, e. *D. Clingani*-zone, g. *P. linearis*-zone. $3^{II'}$ Upper Hartfell Shales—h. *D. complanatus*-zone, i. *D. anceps*-zone. 4^{III} Lower Birkhill Shales—k. *D. acuminatus* and *D. vesiculosus* zones, l. *M. gregarius*-zone. $4^{III'}$ Upper Birkhill Shales—m. *C. cometa*-zone, n. *M. spinigerus*-zone. $4^{III''}$ *R. maximus*-zone. 4 Tarannon series. f. Faults.

Next in order come grey shales and clays yielding no fossils, succeeded by black and grey shales with white clays, forming the zone of *Monograptus spinigerus* (Nich.), containing the following fossils (Fig. 7, $4^{III'n}$):

Monograptus Sedgwicki (Portl.) =*spinigerus* (Nich.)
,, *attenuatus* (Hopk.)
,, *Clingani* (Carr.)
,, *Hisingeri* (Carr.)
,, *spiralis* (Geinitz.)
,, *leptotheca* (Lapw.)

Rastrites hybridus (Lapw.)
Climacograptus normalis (Lapw.)
Petalograptus folium (His.)
Diplograptus tamariscus (Nich.)
,, *Hughesi* (Nich.)
Discinocaris browniana (Woodw.)
Peltocaris aptychoides (Salt.)

Grey mudstones and clays with a thin seam of black shale are then met with, followed by pyritous black shales representing the

zone of *Cephalograptus cometa* (Geinitz), yielding the fossils given below (Fig. 7, $4^{III\,/\,m}$):

Cephalograptus cometa (Geinitz.)
Monograptus lobiferus (M'Coy.)
,, *leptotheca* (Lapw.)
,, *cyphus* (Lapw.)
,, *argutus* (Lapw.)
,, *Hisingeri* (Carr.)
,, *tenuis* (Portl.)
Rastrites hybridus (Lapw.)
,, *capillaris* (Carr.)
Diplograptus tamariscus (Nich.)
,, *sinuatus* (Nich.)
,, *Hughesi* (Nich.)
Petalograptus folium (His.)

To the foregoing strata succeed black flaggy shales and mudstones with clays and occasional ironstone nodules, forming the upper members of the Lower Birkhill group. These beds are of considerable thickness and belong to the zone of *Monograptus gregarius* (Lapw.). From the exposure of this horizon in the main stream the following fossils were obtained (Fig. 7, $4^{III\,1}$):

Monograptus gregarius (Lapw.)
,, *cyphus* (Lapw.)
,, *Sandersoni* (Lapw.)
,, *triangulatus* (Hark.)
,, *leptotheca* (Lapw.)
,, *lobiferus* (M'Coy.)
,, *attenuatus* (Hopk.)
,, *tenuis* (Portl.)
Climograptus innotatus (Nich.)
,, *normalis* (Lapw.)
Diplograptus (*Dimorphograptus*) *confertus* (Nich.)
Rastrites peregrinus (Barr.)
Petalograptus folium (His.)
Discinocaris browniana (Woodw.)
Dawsonia campanulata (Nich.)

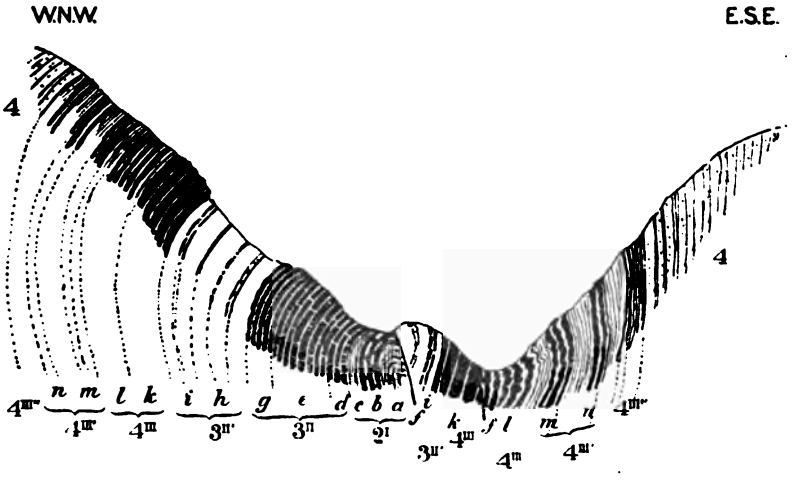


FIG. 8.—Section of Strata in Dobb's Linn (No. 3 of Fig. 5).

(For explanation, see Fig. 7.)

The lower zones of the Birkhill black shales are not satisfactorily seen in the lateral gorge, owing to the presence of a small fault crossing that stream in a north and south direction; but in the corrie to the north they are well displayed, with their characteristic fossils. The hard black flaggy shales representing

the zone of *Diplograptus vesiculosus* (Nich.) there yielded the following forms (Fig. 9, $4^{III\,k}$):

Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus Swanstoni (Lapw.)
Climacograptus rectangularis (M'Coy.)
Monograptus attenuatus (Hopk.)
,, *tenuis* (Portl.)
,, *gregarius* (Lapw.)

Underlying the foregoing beds in the corrie are the shattery black and brown shales belonging to the horizon of *Diplograptus acuminatus* (Nich.), which have yielded also *Dimorphograptus Swanstoni* (Lapw.), *Climacograptus rectangularis* (M'Coy), *Dawsonia campanulata* (Nich.).

The various zones just described constitute the Birkhill division of the Moffat black shale series. The lowest zone (*D. acuminatus*, Nich.), resting directly on the Barren Mudstones, forms the base line of the Llandovery formation.

Returning to the lateral gorge, we meet with the Barren Mudstones (Fig. 7, 3^{II}) in conjunction with the lower members of the Birkhill group, but owing to the small fault already referred to the highest bands with *Dicellograptus anceps* (Nich.) are absent. They are found, however, in good exposures in the corrie north of the gorge and also in the Main Cliff, where the thin black seams in the mudstones have yielded *D. anceps* and *Climacograptus bicornis* (Hall). To these beds succeed the mass of pale-coloured mudstones, with occasional limestone nodules, which, near their base, include a thin seam of black shale containing *Dicellograptus complanatus*, *Diplograptus socialis*, *Climacograptus scalaris* (Fig. 7, $3^{II\,h}$). Underneath the Barren Mudstones come black slaty shales with *Pleurograptus linearis* (Carr)—the highest zone of the Hartfell black shales (Fig. 7, $3^{II\,g}$). This important horizon can be traced up the cliff to the north of the lateral gorge and along the Main Cliff to the south of that section. From these various exposures the following forms have been obtained:

Pleurograptus linearis (Carr.)
Amphigraptus divergens (Hall.)
Leptograptus capillaris (Carr.)
,, *flaccidus* (Hall.)
Retiolites (*Neurograptus*) *fibratus* (Lapw.)
Dicellograptus Morrisi (Hopk.)
,, *elegans* (Carr.)
Diplograptus foliaceus (Murch.)
,, *quadrimucronatus* (Hall.)
Climacograptus tubuliferus (Lapw.)
Siphonotreta micula (M'Coy.)

Next in order we find the black slaty shales of the *Dicranograptus Clingani* zone (Figs. 7, 8, 9, $3^{II\,e}$) visible in the lateral gorge, in the cliff to the north and also in the Main Cliff, which have yielded the following forms:

Dicranograptus Clingani (Carr.)
,, *Nicholsoni* (Hopk.)
,, *ramosus* (Hall.)
Dicellograptus Forchhammeri (Geinitz.)
,, *caduceus* (Lapw.)
,, *moffatensis* (Carr.)
Amphigraptus radiatus (Lapw.)
Lasiograptus margaritatus (Lapw.)
Leptograptus flaccidus (Hall.)
Diplograptus truncatus (Lapw.)
,, *foliaceus* (Murch.)
Climacograptus bicornis (Hall.)
,, *caudatus* (Lapw.)
Corynoides calycularis (Nich.)
Hyalostelia fasciculus (M'Coy), glass-rope sponge.
Acrotreta Nicholsoni (Dav.)

The lowest zone of the Hartfell black shales *(Climacograptus Wilsoni)* is best seen on the slope at the foot of the Main Cliff—an exposure to be referred to presently. On the south bank of the lateral gorge, where it joins the main stream, there is a small rocky knoll at the edge of the alluvium, composed of black flinty shales with cherty bands resembling lithologically the Glenkiln Shales. The forms obtained from them include *Dicranograptus zic-zac* and *D. ramosus*. Here the main or west fault crosses the burn, on the east side of which the evidence is obscured by the alluvium. Eastwards along the section line No. 2 of Fig. 5 the observer crosses the east fault (Fig. 7) and traverses the eastern limb of the arch, which there displays the *Monograptus gregarius* bands in a highly contorted form, and the various zones of the Upper Birkhill Shales, followed in normal order by the greywackes and shales of Tarannon age.

A section across the arch near the south end of the Main Cliff (Fig. 8, Sec. 3 in Fig. 5) shows on the west limb a regular descending sequence from the Upper Birkhill zones to the Glenkiln black

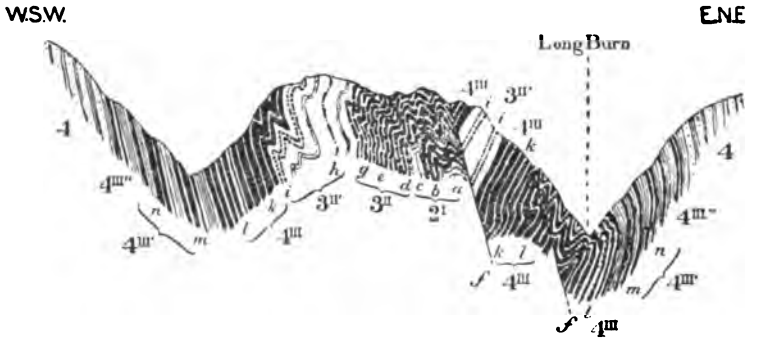


Fig. 9.—Section in Dobb's Linn (No. 1 of Fig. 5).
For explanation, see Fig. 7.

shales, with a normal dip to the W.N.W. Here the representatives of the Glenkiln Shales are met with; indeed, it is the only clear exposure of the latter division in the Dobb's Linn anticline. At the foot of the scar the *Climacograptus Wilsoni* band, the lowest zone of the Hartfell black shales, can be followed for several yards along its line of outcrop, where it yields fine examples of that zonal form, together with *Climacograptus bicornis, C. Schärenbergi, Diplograptus foliaceus, Glossograptus Hincksi, Cryptograptus tricornis.* This zone is underlain by nearly three feet of black shales, which, from their organic remains, may be regarded as the highest zone of the Glenkiln division. From this band the following forms were obtained:

Climacograptus bicornis (Hall.)	*Dicranograptus zic-zac* (Lapw.)
,, *cælatus* var. *antigurus* Lapw.)	*Dicellograptus sextans* (Hall.)
	Cryptograptus tricornis (Carr.)

The foregoing sub-division has been recognised in the sections at Craigmichan Scaurs and Hartfell, where it occupies a similar position, that is, immediately below the *C Wilsoni* band, and above a zone of mudstones and cherts with radiolaria.

At the foot of the Main Cliff at Dobb's Linn, a zone of grey mudstones and cherts with radiolaria, four feet thick, appears below the highest sub-division of the Glenkiln Shales (Fig. 8, 2^{1c}), and it there rests on a band of black shales eight feet in thickness, which have yielded the following forms characteristic of the Glenkiln division:

Dicranograptus zic-zac (Lapw.)
,, *formosus* (Hopk.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
,, sp.
Dicellograptus patulosus (Lapw.)
,, *divaricatus* (Hall)
,, *sextans* (Hall.)
,, sp.
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Nich.)
Didymograptus serratulus (Hall.)
Clathrograptus cuneiformis (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
,, *angustifolius* (Hall.)
,, *per-excavatus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *celatus* var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
,, *peltifer* (Lapw.)
Corynoides calycularis (Nich.)
Dictyonema moffatense (Lapw.)

The Glenkiln black shales just described are truncated by the main or west fault, which brings them in contact with the Barren Mudstones (Fig. 8, 3^{11}), succeeded by the black shales of the Lower Birkhill group, with *Diplograptus vesiculosus* and *Monograptus gregarius* (4^{111}). Eastwards they are followed by the clays and black shales of the Upper Birkhill group with their characteristic forms ($4^{111'}$, $4^{111''}$), though, owing to the weathering of the beds on the east cliff, the fossils are not so readily obtained. These pass normally upwards into the greywackes and shales of Tarannon age.

The Long Burn (Fig. 5) shows an excellent section of the members of the Birkhill division. At its northern limit the black flags of the *D. vesiculosus* zone are exposed; bounded on the east side by the *M. gregarius* bands, which are inverted. Down stream, the beds belonging to the latter horizon are always succeeded on the east side by the Upper Birkhill Shales: the higher zones appearing at intervals underneath the greywackes and shales of Tarannon age. On the west bank of the Long Burn a thin lenticular band of black grit is intercalated in the *Monograptus gregarius* zone, which is traceable for some distance along the cliff. Apparently it dies out rapidly, for it has not been detected on this horizon in any other part of the Dobb's Linn anticline.

On referring to Section 1 of the ground-plan (Figs. 5 and 9), which shows the relations of the strata in the lower part of the Long Burn and in the corrie to the north of the lateral gorge, it will be seen that on the west limb of the fold there is a descending section, in inverted order, from the Tarannon greywackes and shales, through the various zones of the Birkhill division and the Barren Mudstones to the Hartfell black shales. Here the main

fault in the core of the arch appears, which truncates the Hartfell Shales (3^{II}) and brings in to the east, in normal order, the three zones of the Lower Birkhill group (4^{III} in section). Between the main fault and the Long Burn the structure along this line of section is interesting, for the Barren Mudstones ($3^{II'}$) with the *Dicellograptus anceps* band come to the surface, evidently along a minor fold in the Birkhill Shales, on the rocky slope on the west bank of the Long Burn. At the northern limit of this exposure of Barren Mudstones the *D. acuminatus* and *D. vesiculosus* bands can be traced round the end of the fold (Fig. 5) till they are abruptly cut off by the east fault, which for a short distance runs parallel to the course of the main or west fault.

Passing eastwards along the same line of section, across the Long Burn, where the *Monograptus gregarius* bands are puckered and inverted, the observer finds the Upper Birkhill shales ($4^{III'}$ $4^{III''}$, Fig. 9) followed in normal order by the greywackes and shales of Tarannon age.

The north-easterly extension of Dobb's Linn anticline is obscured by peat and drift, but it probably terminates not far to the north of the present visible exposure of black shales.

Summary.—From the foregoing descriptions it will be seen that a detailed examination of Dobb's Linn section proves the accuracy of Professor Lapworth's conclusions regarding the sequence and geological relations of the strata. The various subdivisions of the Moffat series (Birkhill, Hartfell, and Glenkiln), which are lithologically and palæontologically distinct, are there arranged in the form of an arch, the highest zones of the Birkhill Shales being in contact with the overlying Tarannon greywackes and shales on both limbs of the fold. As the observer passes towards the centre of the anticline, the different zones are met with in descending order, till on the western limb at the foot of the Main Cliff there is an exposure of the Glenkiln Shales with an intercalated band of radiolarian cherts and mudstones. The natural sequence is, however, interrupted by the main or west fault running along the crest of the arch, which brings different horizons in contact with each other. It is further clear that at the southern limit of the arch (Fig. 6, Sec. 4 in Fig. 5) the axial plane of the fold dips towards the west, and hence the strata on the east limb are inverted; while in the lateral gorge (Fig. 7) the strata on the west limb are inverted.

It is of importance, also, to note that the lowest zone of the Birkhill Shales marks the base of the Upper Silurian rocks of the region, and that while this boundary line coincides with a distinct palæontological break, there is nevertheless a perfect passage from the underlying Hartfell group (Caradoc) into the overlying Birkhill sediments (Llandovery).

Craigmichan Scaurs, Moffatdale.

The order of succession indicated in Dobb's Linn is confirmed in a remarkable manner by the fine section in Craigmichan

Scaurs, which is traceable along the strike for three-quarters of a mile (Fig. 10). In addition to the Birkhill and Hartfell divisions, there is here an excellent exposure of the Glenkiln black shales and the associated mudstones and cherts. The Craigmichan Scaurs occur on the south-east flank of Capel Fell (2223 feet) at the head of the Selcoth Burn, which joins the Moffat Water about seven miles south-west of Dobb's Linn. Though the strata are considerably shattered, and in some instances repeated by reversed faults, the general order of succession can be clearly followed.

On referring to the geological map of the region (Sheet 16) it will be seen that about two miles up the Selcoth Burn from its point of junction with the Moffat Water there is a marked bend in its course. Below this bend it flows north-west towards the Moffat Water; above it, for nearly half a mile, its course is about south-west and north-east, or nearly parallel to the strike of the strata. About half a mile above this bend, the Selcoth Burn is joined by a small tributary (the Rae Grain, Fig. 11, ground plan) draining the south-east slope of Capel Fell. Between the Rae Grain and the great bend in the Selcoth Burn, a deep and rough gorge has been carved in the Moffat series, the members of which form a prominent escarpment on the north-west side of the stream.

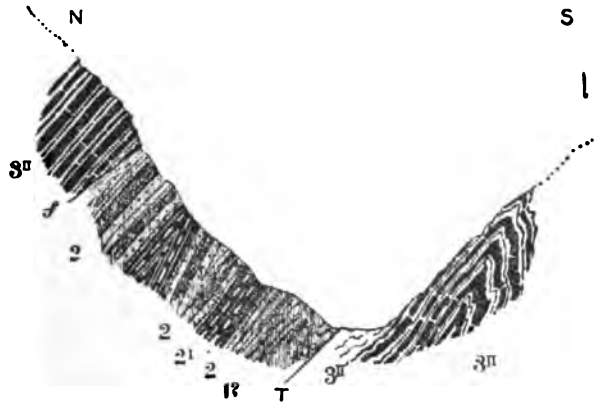


FIG. 10.—Section in Craigmichan Scaurs, Moffatdale.

1. Arenig? 2. Ashy mudstone and radiolarian chert. 2l. Glenkiln Black Shale. 3ll. Lower Hartfell Shale. 3ll′. Barren Mudstones. f Fault. T. Thrust-plane.

In the Selcoth Burn and on the slopes of Capel Fell, the representatives of the black shale series appear along several isoclinal folds dipping to the north-west. The main fold occurs furthest south, its axis nearly coinciding with the course of the stream between the Rae Grain and the great bend in the Selcoth Burn. The physical relations of the strata, so clearly unfolded by Professor Lapworth, may be readily grasped by a study of the various sub-divisions exposed in this great isocline.

The lowest beds forming the core of the arch occur in the bed of the Selcoth Burn and along the base of Craigmichan Scaurs, north-eastwards to the foot of the Rae Grain. The relations of the Glenkiln group to the overlying Hartfell division in Craigmichan Scaurs are illustrated by the accompanying horizontal section (Fig. 10), which is drawn across the gorge above the waterfall in Selcoth Burn.

Beginning on the north cliff, on the horizon of the *Climacograptus Wilsoni* band (3^{II}) at the base of the Lower Hartfell group, we find beneath that band about $2\frac{1}{2}$ feet of black shales which here yield forms similar to those in the thin black

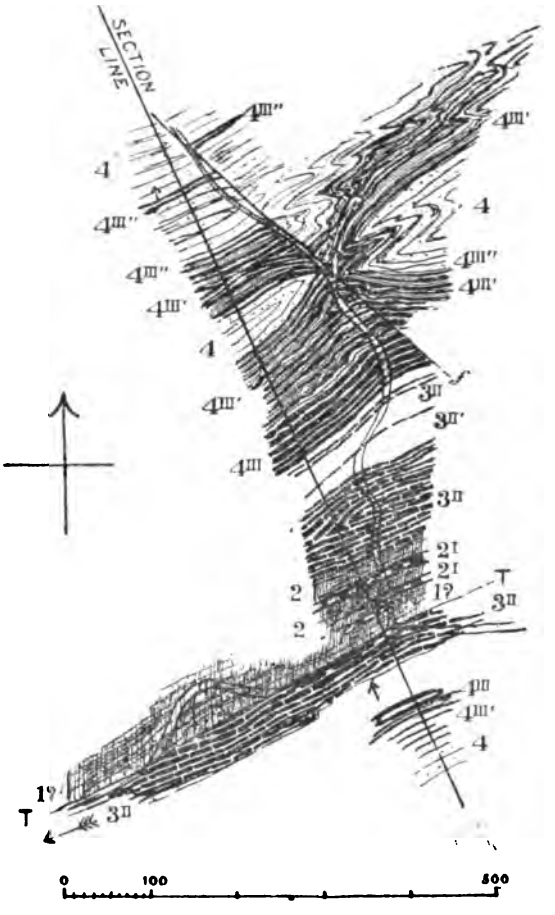


FIG. 11.—Plan of Strata in Rae Grain, Selcoth Burn.

1. Arenig ? 2. Ashy mudstone and chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. $3^{II'}$. Barren Mudstones. $3^{II''}$. *D. anceps*-zone. 4lll. Lower Birkhill Shales. $4^{III'}$. Upper Birkhill Shales. $4^{III''}$. *R. maximus*-zone. 4. Tarannon series. f. Fault. T. Thrust-lane.

shale zone at the top of the Glenkiln group in the Dobb's Linn section. They likewise rest on a prominent mass of mudstones and cherts with radiolaria, the thickness of which cannot be safely estimated owing to the presence of faults. They present the following lithological characters in descending order:

1. Alternations of grey cherty ribs and mudstones.
2. Zone of blue-grey mudstones weathering yellow.
3. Grey ribbed cherts with radiolaria.
4. Yellow, spotted, ashy band, resembling a fine volcanic tuff.

The foregoing succession of cherts and mudstones is apparently much thicker than the corresponding zone in the Dobb's Linn section, but it here rests on a similar mass of black shales with characteristic Glenkiln fossils, which with the mudstones and cherts is repeated by minor folds (Fig. 10). The following assemblage of forms was obtained from these exposures:

Cœnograptus pertenuis (Lapw.)
Thamnograptus typus (Hall.)
Dicranograptus zic-zac (Lapw.)
,, *minimus* (Lapw.)
,, *ramosus* (Hall.)
Diplograptus angustifolius (Hall.)
Climacograptus peltifer (Lapw.)
Dicellograptus patulosus (Lapw.)
Diplograptus foliaceus (Murch.)

The members of the Glenkiln group are succeeded on both sides of the gorge by the Lower Hartfell black shales. As the observer descends the Selcoth Burn from the Rae Grain, towards the bend in the former stream, he finds that the Glenkiln Shales disappear and pass underneath the overlying zones. The succession, however, is not undisturbed, for there seems to be a reversed fault truncating the strata along this part of the stream course—a structural feature to be referred to presently (Figs. 10, 11, and 12).

On the north limb of the fold, on Craigmichan Scaurs, the following forms have been obtained from the *Climacograptus Wilsoni* zone, at the base of the Hartfell group:

Climacograptus Wilsoni (Lapw.)
,, *bicornis* (Hall.)
Dicranograptus ramosus (Hall.)
Glossograptus Hincksi (Hopk.)
Diplograptus foliaceus (Murch.)
Corynoides calycularis (Nich,)

Next in order come the black flaggy shales of the *Dicranograptus Clingani* zone, containing the following assemblage of fossils:

Leptograptus flaccidus (Hall.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
Dicellograptus Forchhammeri (Geinitz.)
,, *moffatensis* (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
,, *caudatus* (Lapw.)
Retiolites (*Neurograptus*) *fibratus* (Lapw.)
Corynoides calycularis (Nich.)

To these beds succeed the black slaty shales that form the highest zone of the Lower Hartfell group, yielding the characteristic forms:

Pleurograptus linearis (Carr.)
Leptograptus flaccidus (Hall.)
Dicellograptus Morrisi (Hopk.)
,, *elegans* (Carr.)
Climacograptus tubuliferus (Lapw.)
Diplograptus quadrimucronatus (Hall.)

Overlying these fossiliferous zones comes a fine development of the Barren Mudstones, which can be traced from the bend in the Selcoth Burn along the north-west limb of the anticline for half a mile. Owing to their peculiar mode of weathering, their outcrop can readily be followed along this magnificent crag, where they are overlain by the members of the Birkhill group. When the Hartfell black shales and the Barren Mudstones are followed along the strike south-westwards along Craigmichan Scaurs to the great bend in the Selcoth Burn, they are there seen to be truncated by a reversed fault which is probably the continuation of that at the foot of the Rae Grain. A few yards north of the bend this dislocation is succeeded by several small reversed faults trending towards the north-west, which repeat slices of the Hartfell black shales and the overlying Barren Mudstones (Fig. 13, 3^{II} $3^{II\prime}$).

Next in order, above the Barren Mudstones, come the members of the Birkhill group, which are exposed on both sides of the arch. On the south limb of the main isocline, near the bend in the Selcoth Burn, the black flaggy shales of the lower division yielded specimens of *Diplograptus vesiculosus* (Nich.), *Climacograptus innotatus* (Nich.), *C. normalis* (Lapw.), *Monograptus tenuis* (Portl.); while the overlying sub-zone there furnished *Monograptus gregarius* (Lapw.), *M. lobiferus* (M'Coy), *M. triangulatus* (Hark.), *M. spiralis* (Geinitz), *Climacograptus normalis* (Lapw.).

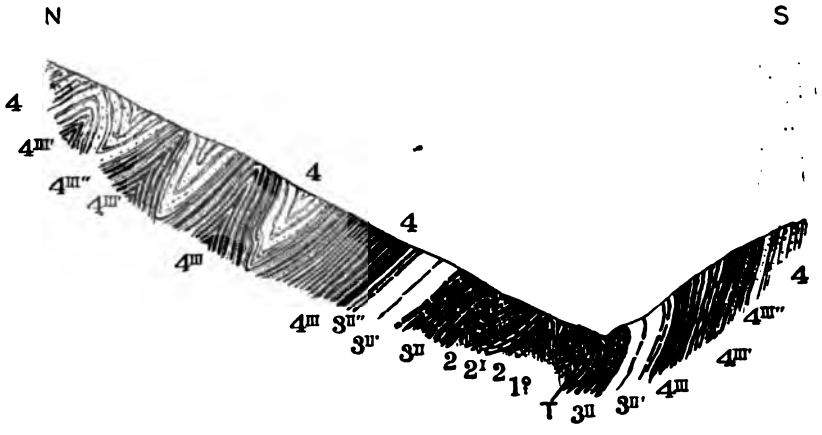


FIG. 12.—Section in Rae Grain, Selcoth Burn.
(For explanation, see Fig. 11.)

The greywackes and shales of Tarannon age are found in regular order above the highest zone of the Birkhill Shales in Craigmichan Scaurs, and also on the south-east limb of the anticline. High up on the slope of Capel Fell and along the great crag of Craigmichan Scaurs, a second isoclinal fold of no great breadth can be traced, revealing only the Birkhill Shales

The evidence regarding the relations of the Moffat series to the overlying greywackes and shales obtained from the section in Rae Grain still further confirms the foregoing order of succession (Figs. 11 and 12). The axis of the great isoclinal fold on Craigmichan Scaurs is prolonged north-eastwards to the foot of the Rae Grain, where the Glenkiln black shales and the associated mudstones and cherts with radiolaria are exposed (2, 2^{I} in section, Fig. 12). On the south side they are truncated by a reversed fault, whereby they are made to overlie the Lower Hartfell black shales on the south limb of the fold (3^{II}). Northwards in the Rae Grain the members of the Glenkiln group are overlain by folded and crumpled slaty black shales with characteristic Lower Hartfell forms (3^{II}, Fig. 12), followed by an exposure of decomposing brown and grey shales and mudstones representing the Barren Mudstones. Next in order come the black flaggy shales charged with *D. vesiculosus* (4^{III}, Fig. 12), succeeded by the Upper Birkhill zones, which plunge underneath the greywackes and shales of Tarannon age. On referring to the ground-plan (Fig. 11), it will be seen how the latter are thrown into sharp synclinal folds to the north-west of the main isocline, being there underlain by the *Rastrites maximus* zone of the Upper Birkhill Shales. It is evident, therefore, that no great thickness of Tarannon greywackes and shales intervenes between the successive isoclines of the black shale series in Craigmichan Scaurs and Capel Fell.

Turning now to the south limb of the fold at the foot of Rae Grain (Fig. 12), we notice that the Lower Hartfell black shales, which are there much shattered and contorted, are succeeded by the Barren Mudstones. Next in order come the members of the Birkhill division (4^{III}, $4^{III'}$) with an inverted dip to the north-west, followed by the Tarannon greywackes and shales.

One of the striking features in the section in the Selcoth Burn below the great bend is the repetition of the Birkhill Shales by a succession of sharp isoclinal folds in the midst of the Tarannon greywackes and shales, which have been figured and described by Professor Lapworth in his paper on "The Moffat Series."* The accompanying ground plan and series of horizontal sections (Fig. 13) illustrate the relations of the strata. Here there are six isoclinal folds, each dipping to the north-west, revealing some of the Birkhill zones amid the overlying flags and shales. The south-east limb of each arch is truncated by a reversed fault whereby different zones of the Birkhill Shales are made to overlie the Tarannon flags and shales. The most northerly isocline occurs about 600 yards down stream from the great bend in the Selcoth Burn (Section 1, Fig. 13), where on the north side of the arch about 24 feet of stained shales appear, which are streaked with white clays and dark seams, the latter being charged with *Rastrites maximus*. These are underlain by

* Quart. Jour. Geol. Soc., Vol. xxxiv., p. 264.

lower zones of the Upper Birkhill division, which are abruptly truncated by a reversed fault. In Sections 3 and 4 (Fig. 13) the Lower Birkhill Shales are likewise represented in the centre of the isoclines, many forms characteristic of the *Monograptus*

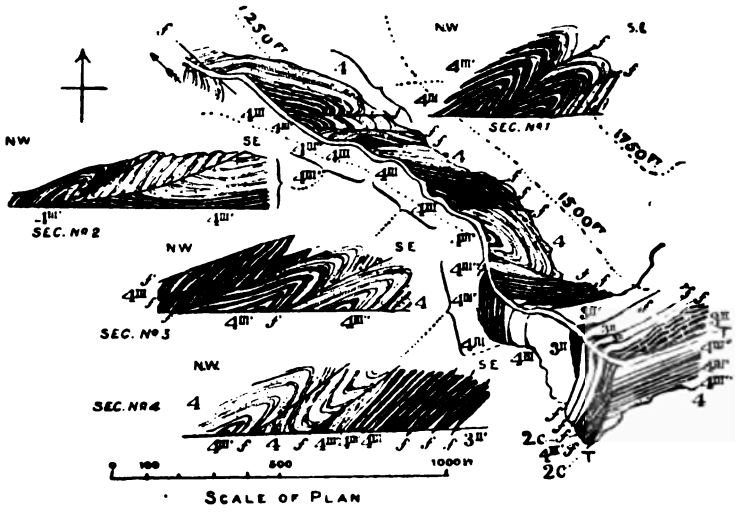


FIG. 13.—Plan and Sections in Selcoth Burn.

2c. Glenkiln chert. 3ll. Lower Hartfell Shales. 3ll′. Barren Mudstones. 4lll. Lower Birkhill Shales. 4lll′. Upper Birkhill Shales. 4lll″. *R. maximus*-zone. f. Reversed Faults. T. Thrust-plane.

gregarius and *Diplograptus vesiculosus* zones being here obtainable. Indeed the horizons of the various bands in the successive anticlines can be readly determined by the included fossils, though in some instances the individual zones are thrust against each other. The following forms have been obtained from the black seams associated with white clays belonging to the *M. spinigerus* zone of the Upper Birkhill division in one of these isoclinal folds:

Monograptus spinigerus (Nich.)
,, *Hisingeri* (Carr.)
,, *jaculum* (Lapw.)
,, *Sandersoni* (Lapw.)
,, *leptotheca* (Lapw.)
,, *tenuis* (Portl.)
Monograptus Clingani (Carr.)
Diplograptus sinuatus (Nich.)
,, *tamariscus* (Nich.)
Petalograptus folium (His.)
Peltocaris aptychoides (Salt.)

In describing these isoclines, Professor Lapworth called attention to the fact that the angle of inversion of the axial planes "decreases in proportion as we pass outwards from the chief anticlinal line," or, in other words, as we descend the stream towards the northmost fold.

From the evidence supplied by the great anticlinal fold in Selcoth Burn and Craigmichan Scaurs, it is clear that the

sequence of the Moffat series described in the foregoing paragraphs is placed beyond dispute. The distinctive lithological and palæontological features, so apparent in Dobb's Linn, are no less marked in the sections just described. As yet there is no indication of any change in the physical conditions which mark certain zones to the north-west and south-east of the typical Moffat area.

CHAPTER VI.

THE CENTRAL BELT—*continued.*

BLACK SHALE BANDS SOUTH OF MOFFATDALE.

HAVING indicated the order of succession in the Moffat black shales, we shall now proceed to describe the various outcrops of the series in the region lying to the south-east of St. Mary's Loch and Moffatdale. A glance at the map (Sheet 16) will show that in the narrow belt of high ground between the Moffat Water and the Lower Ettrick there is a series of persistent bands of the black shales running more or less parallel to each other and coming to the surface along sharp anticlinal folds. The belt of territory along which these bands can be traced extends from the Permian basin of Moffat at Bellcraig to the vale of Yarrow, a distance of 18 miles.

i. The Band of Bodesbeck Summit, Range Cleuch, Muckra, and Crosscleuch, St. Mary's Loch.

At the south-west termination of this band, which is traceable for a distance of 10 miles, there is a well-marked isoclinal fold in the black shales about 100 yards north-east of the road on Bodesbeck summit. Only the highest bands of the Birkhill Shales are visible in the heart of the greywackes and shales, the strata dipping to the north-west.

Range Cleuch.—Towards the north-east along the outcrop, the members of this series are again visible in the Range Cleuch, a tributary of the Upper Ettrick. Here, in a beautiful isoclinal fold, the various subdivisions are clearly defined where two streams unite to form the Range Cleuch. In the centre of the anticline the black shales belonging to the Lower Hartfell horizon appear, and these are succeeded in regular order by the Barren Mudstones yielding near the top the characteristic form *Dicellograptus anceps.* To these succeed the flaggy shales containing the Lower Birkhill graptolites, followed by the clays, grey and black shales forming the upper portion of this group. The highest bands in contact with the greywackes on both limbs of the arch yield *Rastrites maximus* and *M. Sedgwicki.* The strata are considerably crumpled, but the sequence is none the less apparent.

Rowantree Gutter.—Further to the north-east in a small cleugh flowing into the Kirkhope Burn there is a similar

isocline showing the Hartfell black shales in the core of the arch, which have yielded the following forms:

Pleurograptus linearis (Carr.)	*Climacograptus bicornis* (Hall.)
Leptograptus flaccidus (Hall.)	*Dicellograptus pumilus* (Lapw.)
Diplograptus foliaceus (Murch.	,, *Forchhammeri* (Geinitz.)
,, *truncatus* (Lapw.)	,, *moffatensis* (Carr.)

These are succeeded by the Barren Mudstones and the Birkhill Shales. On the south limb of the fold the greywackes and shales follow in regular order, but on the north limb the natural sequence is disturbed by a fault.

Brockhope Burn.—An instructive section is met with near the head of this stream showing how the Moffat black shales gradually "nose out" or disappear under the overlying greywackes as we ascend the slope to higher ground. In the Brockhope Burn the isoclinal fold reveals the Upper Birkhill zones, with the white clays, grey shales, and black shales, the highest bands on either side yielding *Rastrites maximus* and *Monograptus Sedgwicki*. But as we ascend the streamlet on the east bank (the Overscar) the zones gradually coalesce till at the 1750ft. contour line they pass underneath the Tarannon greywackes.

Trow Grain.—Still further to the north-east two streams unite to form the Back Burn, which joins the Ettrick at Brockhoperig. At the junction of the streams, the isoclinal fold again appears, with the Lower Birkhill bands in the centre and the higher zones on either side. From these exposures the following forms have been obtained: *Monograptus leptotheca* (Lapw.), *M. triangulatus* (Hark.), *M. lobiferus* (M'Coy), *M. spiralis* (Geinitz), *Rastrites maximus* (Carr.).

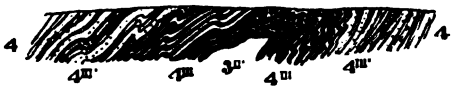


FIG. 14.—Section in Trow Grain, Ettrick Water.

3II'. Barren Mudstones. 4III. Lower Birkhill Shales. 4III'. Upper Birkhill Shales. 4. Tarannon series.

Not far to the east, in the Fala Grain, this isoclinal fold is further demonstrated by the appearance of the Barren Mudstones in the core of the arch, bounded on either side by the flaggy black shales containing *Diplograptus vesiculosus* and *Monograptus gregarius*, succeeded by the grey shales, clays, and dark seams of the Upper Birkhill group.

Far up the south slope of Herman Law, in a streamlet flowing into the Black Grain and also in the latter stream, there is an exposure of the Upper Birkhill beds in the midst of the greywackes. In the main stream these zones are repeated by several sharp folds, but in the small tributary only one is seen. At one

locality the fossils are in a fine state of preservation. Those obtained are given in the following list:

Monograptus Sedgwicki (Portl.)	*Rastrites peregrinus* (Barr.)
,, *attenuatus* (Hopk.)	,, *distans* (Lapw.)
,, *spiralis* (Geinitz.)	,, *capillaris* (Carr.)
,, *leptotheca* (Lapw.)	

In the Muckra Burn the north-east prolongation of this band is visible, but in part of this section the black shales are very much shattered and crushed, so that it is difficult to interpret the sequence with certainty. The lowest beds exposed seem to represent the Barren Mudstones overlain by the Lower Birkhill Shales. Towards the north, the upper beds of this division are repeated by folds, and yield *Monograptus spinigerus*, *M. Hisingeri*, *M. Sedgwicki*, and *Rastrites maximus*. On both sides of the anticline they plunge underneath the Llandovery greywackes.

Again at Crosscleuch, near St. Mary's Loch, only the Birkhill beds are represented, there being two small anticlines with an intervening syncline of greywackes.

ii. Band of Thirlstane Score.

Not far to the south of the band just described, and about a mile to the east of St. Mary's Cottage at the south end of St. Mary's Loch, a small anticline in the black shale series is traceable for no great distance. The section is visible in a small stream flowing into the Thirlstane Burn. The lowest beds exposed belong to the lower portions of the Birkhill group, and form the core of the arch. They yield *Diplograptus acuminatus*, *D. vesiculosus*, and *Monograptus gregarius*. These are succeeded by the black and grey shales and mudstones, partly of a purple colour, charged with *M. spinigerus*, followed in order by the highest bands containing *Rastrites maximus* and *Monograptus Sedgwicki* in excellent preservation. An intrusive felsite dyke is traceable along the north-west limb of the fold. The anticline is inverted, and the various zones succeed each other regularly on both sides of the arch. But in the intervening area the sequence is disturbed by a normal fault. On the east limb of the fold, the anticline of the Lower Birkhill zones is truncated by a normal fault bringing down higher members of this division into conjunction with the lower.

iii. Band extending from Pot Law by Peniestone Knowe to Moory Sike: probable continuation towards the south-west from Capel Fell to Craig Fell.

For a distance of eight miles this band is traceable between Pot Law and Moory Sike; but towards the south-west, after a gap of about a mile and a half, a band of black shales appears much on the same line of strike, extending for three miles from Capel Fell to Craig Fell.

Cossarshill Burn.—About a mile and a half to the east of Birkhill,, an interesting transverse section of this band is to be seen in a small stream at the head of Cossarshill Burn, a tributary of the Ettrick. At the northern end the grey shales with dark seams containing *Rastrites maximus* dip below the Tarannon greywackes and shales at high angles. Descending the section, these higher zones with black seams and white clays are repeated by sharp inverted folds. Soon the hard black flaggy shales, charged with *Diplograptus vesiculosus*, rise from underneath them. These Lower Birkhill beds are cut off on the south side by a fault that brings them into contact with the Tarannon flags and shales. Further down the section we meet with three successive anticlines of the Birkhill beds belonging to the higher zones, the intervening synclines being occupied by flags and shales.

Further to the north-east this band is exposed in the Riskinhope Burn, which flows for some distance along the strike of the beds. At the head of the stream the grey and black shales appear, charged with *Rastrites maximus*, but further down the sections lower horizons come to the surface. The flaggy shales with *Diplograptus vesiculosus* and *Monograptus gregarius* are met with, and at one point there is a small exposure of the Lower Hartfell black shales in the midst of the Barren Mudstones.

Moory Sike.—Further to the north-east, a fine transverse section of this band is found in the Moory Sike, a tributary of the Whitehope Burn flowing into the Loch of the Lowes.

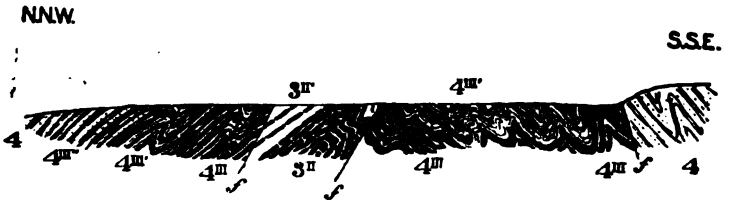


FIG. 15.—Section in Moory Sike, above Loch of the Lowes. (Length, 150 yards.)

3II. Lower Hartfell Shales. 3II'. Barren Mudstones. 4III. Lower Birkhill Shales. 4III'. Upper Birkhill Shales. 4III''. *R. maximus*-zone. 4. Tarannon series. f. Fault.

At the south end of the section, at the waterfall, the greywackes and shales are brought into contact with some of the Birkhill zones by a fault. Close to the fault, dark shales appear, alternating with white clays, and dipping to the south. These are followed by the black flaggy shales of the *Diplograptus vesiculosus* zone. For a short distance there is an exposure in a highly contorted form of grey shales, blue clays with black shales, and white clays representing the higher members of the Birkhill group. Further north the black flaggy shales again appear belonging to the *Diplograptus vesiculosus* zone. These

are faulted against the Lower Hartfell black shales and a small portion of the Barren Mudstones. The Hartfell black shales are highly contorted, but they seem to be arranged in an anticlinal fold, for the Barren Mudstones reappear on the north side of the fold. Several of the characteristic zones can be proved by means of the fossils. The lowest bands yield *Climacograptus Wilsoni* and *Dicranograptus Clingani*, *D. ramosus*, and *Corynoides calycularis*. The highest zone, *Pleurograptus linearis*, is met with, and towards the north it plunges below the Barren Mudstones with black seams yielding *Dicellograptus anceps*.

By means of a fault the Barren Mudstones are brought into conjunction with the Upper Birkhill beds. These consist of grey shales with black bands yielding *Monograptus spinigerus* and *M. Hisingeri*. Further north these pass upwards into the grey shales with white clay bands of the *Rastrites maximus* zone, which are repeated by means of small folds.

Though this section is disturbed by faults, yet it is sufficiently clear that the lowest beds exposed in the core of the arch belong to the Hartfell black shales, succeeded by the Barren Mudstones. The Birkhill beds are also found on both limbs of the anticline, and on the north side they pass gradually upwards into the Tarannon flags and shales.

iv. Band extending from Brockhope Burn by Whitehope and Berryknowe to Eldinhope in the Vale of Yarrow.

This band is traceable for a distance of nine miles from the basin of the Upper Ettrick to the Vale of Yarrow.

Black Grain.—One of the chief sections across this band is exposed in the Black Grain, a small tributary of the Back Burn joining the Ettrick at Brockhoperig. At the northern limit of the section, grey and purple shales with dark seams are associated with flaggy shales and greywackes which evidently represent the higher zones of the Birkhill division. These dip to the north-west at high angles. Rising from underneath these beds come the black flaggy shales of the *Diplograptus vesiculosus* zone, forming a flat arch truncated on the south side by a fault bringing in the grey flags and shales overlying the highest Birkhill zones. Descending the stream, the grey and purple shales with dark seams appear passing downwards into the gnarled and flaggy black shales of the *Diplograptus vesiculosus* zone.

These are underlain by a small exposure of the Barren Mudstones, which, yielding *Dicellograptus anceps* and *Diplograptus truncatus*, form the centre of the arch. On the south side of the fold they are followed in natural sequence by the black flags of the *D. vesiculosus* zone. Overlying the Lower Birkhill Shales, grey and black shales yield *Monograptus spinigerus*. These beds pass upwards into grey and purple shales with dark seams and white clays, representing the upper portion of this division, from which have been obtained *Rastrites maximus* and *Monograptus*

Sedgwicki. At the south end of the section there is a great cliff of grey flags and shales with greywacke bands, including repetitions of some of the *Monograptus Sedgwicki* bands.

Whitehope Burn.—In this section the Birkhill Shales, ranging from the *Monograptus gregarius* zone to the top of the series, are visible, and though the strata are much disturbed and contorted there is sufficient evidence to show that they are arranged generally in an anticlinal fold.

Eldinhope Burn.—At the north-east termination of this band there is a small exposure in this burn, in which only the highest zones of the Birkhill division appear. On the north, the *Rastrites maximus* bands plunge underneath the greywackes and shales underlain by the *M. spinigerus* zone; while towards the south the highest bands dip below the greywackes.

v. Mountbenger.

An interesting section is met with in this stream close by the road in the Vale of Yarrow, where the strata are arranged in an anticlinal form. Towards the north the highest zones of the Birkhill division, consisting of grey and purple shales with black seams and white clays, pass underneath the greywackes and shales. They contain in admirable preservation the characteristic forms, *Rastrites maximus*, *Monograptus Sedgwicki*, &c. The beds are underlain by black shales representing the Lower Birkhill beds. The section is not continuous, but in the centre there seems to be a double fold of the Lower Hartfell black shales with the Barren Mudstones. The horizon of these black shales is evident from the accompanying list of fossils obtained at that locality:

Pleurograptus linearis (Carr.)
Dicellograptus Forchhammeri (Geinitz.)
,, *moffatensis* (Carr.)
,, *caduceus* (Lapw.)
,, *Morrisi* (Hopk.)
,, *elegans* (Carr.)
Leptograptus flaccidus (Hall.)
Climacograptus bicornis (Hall.)
,, *tubuliferus* (Lapw.)
Diplograptus truncatus (Lapw.)
,, *foliaceus* (Murch.)
Siphonotreta micula (M'Coy.)
Acrotreta Nicholsoni (Dav.)

Further south, after a blank in the section, the Birkhill Shales again appear, the lowest consisting of the hard flaggy shales of the *D. vesiculosus* zone, followed by the grey and black shales and clays of the upper portion of the group. From the various exposures of the Birkhill beds at Mountbenger the following forms have been obtained:

Monograptus Sedgwicki (Portl.)
,, *triangulatus* (Hark.)
,, *lobiferus* (M'Coy.)
,, *cyphus* (Lapw.)
Monograptus Hisingeri (Carr.)
,, *leptotheca* (Lapw.)
,, *Sandersoni* (Lapw.)
Rastrites peregrinus (Barr.)

To the south-west of the band of black shales, extending from Altrieve to Brockhope Burn, another has been traced, much in the same line of strike, from that stream to the eastern slope of

Capel Fell—a distance of about four miles. After a gap of about half a mile, a band reappears on the crest of Capel Fell, and can be followed at intervals to Brackenside Burn.

vi. Band extending from Bellcraig by Craigmichan Scaurs, Entertrona, the Upper Ettrick, to Berrybush.

On referring to Sheet 16, it will be seen that between Bellcraig at the edge of the basin of Permian rocks at Moffat and Berrybush, two miles east of the Loch of the Lowes, a band of black shales can be traced more or less continuously. At intervals, owing to the intense plication of the strata, thin portions of the Tarannon greywackes and shales occupy narrow synclinal folds in the Moffat series. Hence it frequently happens that minor anticlines of the black shales branch off from the dominant fold, forming wedge-shaped masses in the Tarannon greywackes. Where, owing to denudation, the latter beds have been removed, the folds are represented in the black shale series. For convenience of description, therefore, the various outcrops of the Moffat Shales along the foregoing line will be regarded as belonging to one general band.

Bellcraig.—The physical relations of the strata in this important section have been worked out by Professor Lapworth. The section occurs partly in the Bellcraig Burn and partly in one of its small branches, the Hodge Burn.

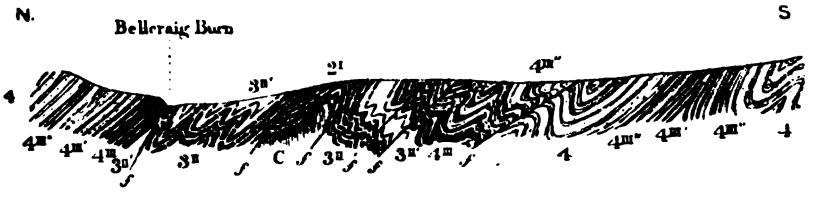


FIG. 16.—Section in Hodge Burn, Bellcraig, Moffat.

C. Radiolarian chert. 2l. Glenkiln Shales. 3II. Lower Hartfell Shales. 3II'. Barren Mudstones. 4III. Lower Birkhill Shales. 4III'. Upper Birkhill Shales. 4III" *R. maximus*-zone. 4. Tarannon series. f. Fault.

Beginning with the transverse section exposed in the Hodge Burn, the observer finds that the beds have a uniform inclination to the north-west, and hence that the fold is isoclinal and the southern limb is inverted. The relations of the highest zones of the Birkhill group to the Tarannon greywackes are clearly seen at the southern limit of the section. There the latter dip to the north-west at angles from 45° to 50°, and are succeeded by flaggy beds and shales with black shales and thin white clays associated with blue shales and black grits. From the black bands the following forms have been obtained, indicating that they belong to the highest zone:

Rastrites maximus (Carr.)
,, *capillaris* (Carr.)
,, *distans* (Lapw.)
Monograptus Sedgwicki (Portl).
,, *Barrandei* (Tullb.)

From the bands representing the *M. lobiferus* sub-zone the fossils given in the accompanying list were got:

Monograptus lobiferus (M'Coy.)
,, *triangulatus* Hark.)
,, *spiralis* (Geinitz.)
,, *proteus* (Barr.)
,, *leptotheca* (Lapw.)
Diplograptus tamariscus (Nich.)
Petalograptus folium (His.)
Dimorphograptus Swanstoni (Lapw.)
Rastrites hybridus (Lapw.)

Next we find the bands yielding *M. gregarius* and the black flaggy shales of the *D. vesiculosus* zone containing the following fossils:

Diplograptus vesiculosus (Nich.)
Climacograptus scalaris (His.) var. *normalis* (Lapw.)
Dimorphograptus Swanstoni (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *gregarius* (Lapw.)
,, *leptotheca* (Lapw.)

To these beds succeed the shattery dark shales of the *D. acuminatus* zone, which are repeated by small folds at the bend of the burn above the old hill-road. This horizon has yielded the following forms:

Dimorphograptus elongatus (Lapw.)
,, *Swanstoni* (Lapw.)
Diplograptus acuminatus (Nich.)
Climacograptus normalis (Lapw.)
Climacograptus, sp.
Diplograptus, sp.
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *Hisingeri* (Carr.)
Dawsonia campanulata (Nich.)

Here a small fault intervenes, bringing the basal zones of the Lower Birkhill division into contact with the Hartfell shales; for in the stream near where it is crossed by the old roadway the black shales yielded these characteristic forms:

Pleurograptus linearis (Carr.)
Leptograptus flaccidus (Hall.)
Dicellograptus moffatensis (Carr.)
,, *elegans* (Carr.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
,, *quadrimucronatus* (Hall.)
Climacograptus tubuliferus (Lapw.)

Immediately to the north of the old roadway in the Hodge Burn the Glenkiln black shales appear in the core of the arch charged with certain typical forms (2^1, Fig. 16):

Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
Didymograptus superstes (Lapw.)
Dicranograptus formosus (Hopk.)
,, *ramosus* (Hall.)
Dicellograptus patulosus (Lapw.)
Dicellograptus divaricatus (Hall.)
,, *sextans* (Hall.)
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Nich.)
Diplograptus mucronatus (Hall.)
Climacograptus bicornis (Hall.)

On their northern margin the Glenkiln black shales are bounded by a fault bringing down the Barren Mudstones, which occupy the lower portion of the section, to a point near the junction of the two streams. There is a fine exposure also of this Upper Hartfell group in the main stream above the junction with the Hodge Burn; the Barren Mudstones are succeeded by black shales yielding *Leptograptus flaccidus* and *Pleurograptus*. These are faulted against the

Birkhill Shales seen at the junction of the streams and in Bellcraig Burn, where they have yielded the following forms:

Diplograptus tamariscus (Nich.)
Petalograptus folium (His.)
Cephalograptus cometa (Geinitz.)
Rastrites peregrinus (Barr.)
,, *distans* (Lapw.)
,, *hybridus* (Lapw.)
Monograptus spiralis (Geinitz.)
,, *Sedgwicki* (Portl.)
,, *triangulatus* (Hark.)
,, *lobiferus* (M'Coy.)
,, *attenuatus* (Hopk.)
,, *leptotheca* (Lapw.)

Below the place where the Bellcraig Burn is crossed by a basalt dyke the Glenkiln black shales are exposed in the centre of the fold, separated on the north-west side from the Barren Mudstones by a fault—evidently a continuation of that seen in the tributary burn. These strata have yielded:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
Thamnograptus typus (Hall.)
Dicranograptus formosus (Hopk.)
Dicellograptus patulosus (Lapw.)
Dicellograptus sextans (Hall.)
Leptograptus flaccidus (Hall.)
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
,, sp.

The Bellcraig anticline of the Moffat Shales can be followed at intervals towards the north-east in the direction of the sources of the Brackenside Burn, and thence to the pass at the head of the Wamphray Water. At the latter locality the strata form a compound anticline. Near the head of the stream the greywackes, shales, and black grits on the south side of the arch dip towards the north-west, succeeded by the Birkhill Shales, Barren Mudstones, and Hartfell black shales with their characteristic fossils, the latter forming the lowest beds exposed. On the north limb of the fold, the Barren Mudstones again appear, followed by the Birkhill Shales, which are thrown into an inverted synclinal fold with Tarannon greywackes and shales in the centre.

From this latter point the outcrop descends to Selcoth Burn and Craigmichan Scaurs, which sections have been described in detail in the previous chapter. Here the Bellcraig and Entertrona band, and the Upper Ettrick and Berrybush band approach each other very closely. From the Selcoth Burn the black shale series can be traced north-east to the Entertrona Burn, one of the tributaries of the Upper Ettrick (Figs. 17, 18).

The section in the Entertrona Burn reveals the presence of black grits in part of the Birkhill division. In the higher part of the stream the greywackes and flags, with zones of shale, dip steadily towards the north-west at angles from 40° to 60°. Descending the section, black grits, grey grits, and black shales with reddened bands, yielding *M. Sedgwicki*, appear along isoclinal folds. These occur to the south of the main outcrop. Further down the stream, about a third of a mile from its junction with the Ettrick, the Birkhill zones are exposed, consisting of grey shales and clays, dark seams, with grey and black grits and greywackes. The dark seams yield *Rastrites maximus*. In the centre of the arch the Glenkiln-Hartfell black shales appear, containing

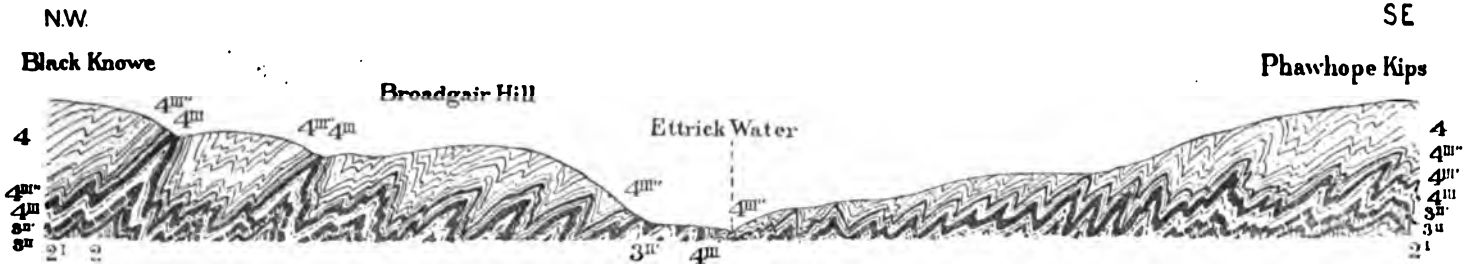


FIG. 17.—Generalised Section from Black Knowe, across Ettrick Water to Phawhope Kips. (Length, two miles.)

2. Glenkiln chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3ll′. Barren Mudstones. 4lll. Lower Birkhill Shales. 4lll′ Upper Birkhill Shales. 4lll″ *R. maximus*-zone. 4. Tarannon series.

FIG. 18.—Generalised Section from Potburn to Ettrick Pen. (Length, one mile and a half.)

C. Radiolarian chert. *(For further explanation, see Fig 17).*

Didymograptus superstes, *Cœnograptus gracilis*, *Dicellograptus*, and *Leptograptus*. On the north side the black grits and shales with *M. Sedgwicki* bands succeed, being visible as we approach Over Phawhope.

Potburn.—Joining the Ettrick at the latter point, we come upon several interesting exposures in the river, downwards to Potburn. Crossing the alluvial flat at Over Phawhope, the Barren Mudstones are found on the right bank of the stream, soon followed by the Hartfell-Glenkiln black shales. In the centre of the fold there is a fine exposure of white cherts with a ribbed mode of weathering representing the radiolarian zone. On the north-west side the black shales reappear, followed by alternations of blue and black shales with white clays and black grits representing the Birkhill zones. The anticline just described between Over Phawhope and Potburn can be followed at intervals south-west to Craigmichan Scaurs and along the Upper Ettrick towards Shorthope and Berrybush.

The accompanying section (Fig. 18) shows the relation of the two anticlines at Entertrona and Potburn, and it further illustrates the dominant isoclinal folding over the region south to Ettrick Pen. The representatives of the Moffat series, occurring on some of these inverted folds south of Entertrona, will be described in the following chapter.

Range Cleuch.—As the anticline is traced down the Ettrick, various exposures of the black shale series are found. At the foot of the Range Cleuch, the Hartfell-Glenkiln black shales appear in the centre of the arch, pierced by a felsite dyke, yielding *Dicranograptus* and *Dicellograptus*. Towards the north they are succeeded by a mass of grey mudstones (Barren Mudstones), followed by black shales representing the Lower Birkhill zones. These are overlain by light greenish shales, black shales, clays, and flags, representing the Upper Birkhill beds.

Again, in the river, opposite Broadgairhill and above Nether Phawhope, the Moffat Shales are visible.

At Shorthope only the Birkhill beds are represented, being repeated by several folds. The lowest beds consist of the black flaggy shales at the base of the group, yielding *Diplograptus acuminatus*, *Diplograptus vesiculosus*, and *Climacograptus normalis*. These are succeeded by blue shales, white clays, and dark seams with black shales representing the upper division, from which the following forms have been obtained:

Monograptus Sedgwicki (Portl.)
,, *attenuatus* (Hopk.)
,, *tenuis* (Portl.)
,, *lobiferus* (M'Coy.)
Petalograptus folium (His.)
Rastrites hybridus (Lapw.)
Peltocaris aptychoides (Salt.)

From the bend of the Ettrick at Shorthope, the band can be traced north-eastwards to the Cossarshill Burn.

Scabcleuch.—Much on the same line of strike, an anticline in the black shales can be traced from Scabcleuch Burn to

Berrybush. In the former stream—a tributary of the Ettrick—a small gorge known as the Slunk has been carved out of the black shale series along the strike of the beds. The lowest bands belong to the *Pleurograptus* zone of the Lower Hartfell black shales, followed by the Barren Mudstones, which in turn are succeeded by the zones of the Birkhill black shales containing *Diplograptus acuminatus* and *D. vesiculosus*. These are followed by grey and yellow clays, shales, and mudstones yielding *Monograptus gregarius*, and towards the top *Rastrites peregrinus*.

Berrybush Burn.—To the north-east in Berrybush Burn the prolongation of this band is met with, the section being of special interest from the fine exposure of Glenkiln beds abundantly charged with their characteristic graptolites.

In the bed of the stream, about half a mile above Berrybush Cottage, the Glenkiln shales dip towards the south-east. Here there is a good development of the cherts and mudstones, representing the radiolarian zone underlying the black shales of this group. The horizon of the black shales associated with them is placed beyond doubt from the following suite of fossils collected at that locality:

Cœnograptus gracilis (Hall.)
Clathrograptus cuneiformis (Lapw.)
Lasiograptus bimucronatus (Nich.)
,, sp.
Didymograptus superstes (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus Whitfieldi (Hall.)
Dicranograptus formosus (Hopk.)
Climacograptus bicornis (Hall.)
Dicellograptus moffatensis (Carr.)
,, *patulosus* (Lapw.)
Leptograptus flaccidus (Hall.)
Acrothele granulata (Linnr.)

Ascending the burn for about half a mile, no rock being visible on the way, the observer finds, high up on the slope of Fall Law, an exposure of the Hartfell group. The various zones of the Hartfell black shales, ranging from the *Climacograptus Wilsoni* zone to that of *Pleurograptus linearis*, are represented, yielding imperfectly preserved fossils. These are overlain by the Barren Mudstones dipping towards the north-west, the highest beds visible in the section.

Much in the same line of strike there is a local exposure of the Moffat Shales near the top of the Eldinhope Burn.

Yarrow Feus.—Again, on the left bank of the Yarrow, near Sunnybank, a small isoclinal fold of the Upper Birkhill Shales dips to the north-west. It is much on the same line of strike as that of the Berrybush band. The areh is well defined, bounded on either side by the Abbotsford flags and shales.

vii. Shorthope and Phawhope, Upper Ettrick.

To the south of the persistent bands of black shales extending from Bellcraig by Craigmichan Scaurs to Berrybush, several local isoclines in the basin of the Upper Ettrick reveal thin seams of black shales associated with black grits and shales, which yield at certain localities specimens of *Rastrites maximus*. Generally these bands are sparingly fossiliferous, and their

horizon is not quite certain; but though they are provisionally regarded as representing higher zones of the Birkhill division, they may, in some cases, belong to the Tarannon series.

In the sections already described in this chapter there are indications of a gradual variation from the normal type of the Birkhill group in Dobb's Linn. The grey shales with black seams and white clays forming the *Rastrites maximus* zone in the latter section are there separated only by a few feet of strata from the underlying graptolite-bearing beds. About a mile and a half to the south-east, in Trow Grain, barren flags and shales intervene between the *Rastrites maximus* bands and the black shales of the Upper Birkhill group. About three-quarters of a mile to the south-east, in the Black Grain—a tributary of the Back Burn—this modification is more pronounced. The thin dark seams, however, containing *Rastrites maximus* (Carr.), though reduced to a fraction of an inch in thickness, are wonderfully persistent, and together with the white clays form a valuable horizon.

River Ettrick below Shorthope. — Eastwards from Shorthope the river Ettrick flows over folded Tarannon greywackes and shales for about two hundred yards, followed by black shale bands which are likewise repeated by flexures. To these succeed black and grey grits with thin black shale partings, also forming sharp undulations.

Shorthope Burn.—In this stream, which is formed by the junction of two small burns (the East Grain and Master Grain) the *Rastrites maximus* bands are found about 50 yards from its junction with the Ettrick. They reappear about 300 yards up the stream associated with black and grey grits and grey greywackes with black shale seams. In the east branch, the *Rastrites maximus* bands occur on successive anticlines; the most southerly one exposing also the underlying black grits and shales. In the west branch (the Master Grain) various folds of thin black seams with *Rastrites maximus* are associated with black and grey grits, black sandy shales, and grey and green mudstones. In both these sections the strata are isoclinally folded, the beds dipping to the north-west at angles varying from 40° to 65°.

Phawhope Burn.—In this stream six sharp anticlines of thin black shale seams are accompanied by strata similar to those referred to in the previous sections. Here they yield one or two Birkhill graptolites (Fig. 17).

Glendearg Burn.—In the deep trench carved by this stream, to the south-west of Phawhope Hill, there is striking evidence of the repetition of these black shale seams by rapid isoclinal folds, for there are upwards of twelve inverted arches exposing bands of this type. The only seams, the horizons of which have been proved by fossils, belong to the *Rastrites maximus* zone, but most of the folds display the associated black and grey grits (Figs. 17 and 18).

Coomb Burn.—In the lower part of this stream, alternations of black grits and shales are visible on the anticlines of

this series. The upper part of the stream is filled with boulder-clay and moraine-drift.

Entertrona.—Attention has already been directed (page 116) to the occurrence of black grits and shales in the main fold in this stream. A few hundred yards further up the burn an inverted fold occurs with thin bands of dark shales and white seams on each side of the arch, belonging to the *Rastrites maximus* zone. In the heart of this isocline we find alternations of grey and black grits with grey and black shale partings.

viii. Ettrickbridge-end Section.

The section exposed in the river Ettrick at Ettrickbridge-end is of great interest and importance, as it shows the extreme

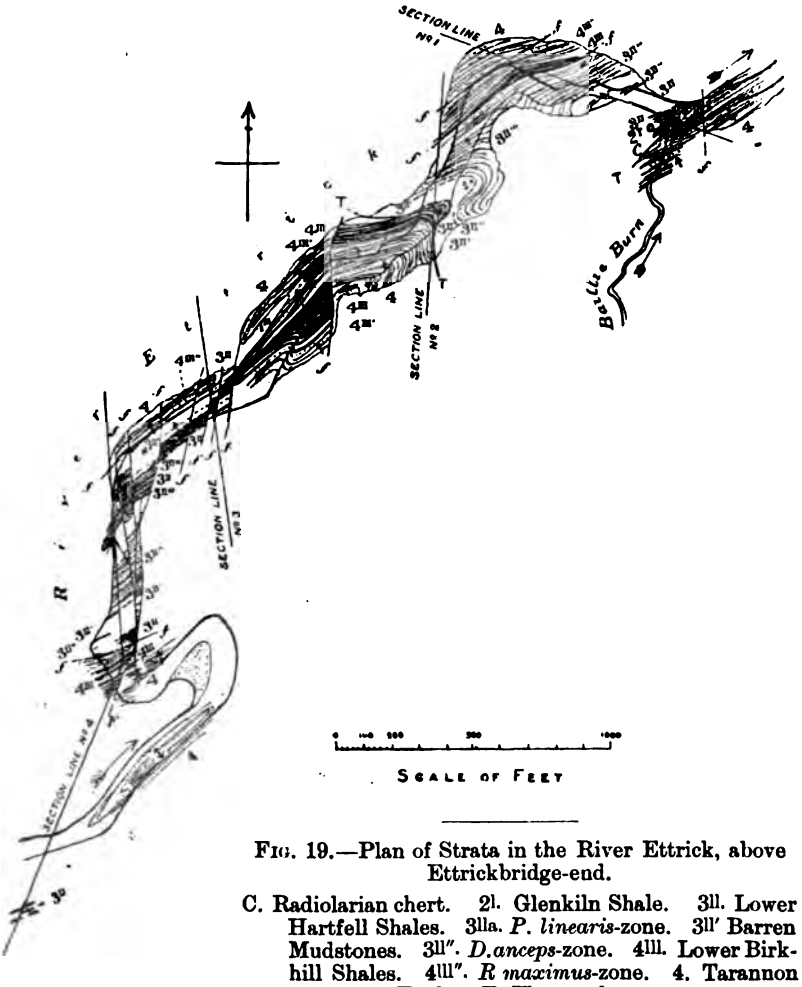


FIG. 19.—Plan of Strata in the River Ettrick, above Ettrickbridge-end.

C. Radiolarian chert. 2l. Glenkiln Shale. 3ll. Lower Hartfell Shales. 3lla. *P. linearis*-zone. 3ll′ Barren Mudstones. 3ll″. *D. anceps*-zone. 4lll. Lower Birkhill Shales. 4lll″. *R maximus*-zone. 4. Tarannon series. f. Fault. T. Thrust-plane.

variations from the normal type of the Moffat series in Dobb's Linn, when traced towards the south-east. The evidence already adduced in this chapter shows that these variations are gradual. Although from the nature of the sharp isoclinal folds, the representatives of the Glenkiln Shales are never brought to the surface to the south-east of the band at Entertrona and the Upper Ettrick, in the Ettrickbridge-end section the Glenkiln black shales and radiolarian cherts are visible, so that we have here representatives of the three great divisions of the Moffat series.

The physical relations of the strata are, however, extremely complicated owing to the occurrence of isoclinal folds and reversed faults. Indeed at one locality the south limb of the fold has been removed by a reversed fault, so that at first it would appear as if we had an ascending sequence from the brown flags and shales on the south into the Glenkiln beds.

From the ground-plan (Fig. 19) and horizontal sections (Figs. 20, 21, 22, 23) the variations in the sequence of deposits may be readily grasped. The greater portion of the grey shale group of the Upper Birkhill division has disappeared, and has been replaced by greywackes, flags, and shales forming the Abbotsford flag series. A band of blue-black shale occurs at the foot of the cliff below the manse of Ettrickbridge-end which yields the fossils of the *Rastrites maximus* zone; but the relations of this band to the Lower Birkhill beds are not clearly displayed at this point. Its horizon must be from 10 to 20 feet higher than a black shale yielding the Lower Birkhill forms. It is also cut off from the Abbotsford flags by a fault with a downthrow to the north-west. But from other evidence it is probable that this band is interleaved in the Abbotsford flags. In the Lower Birkhill group a portion of the *Monograptus lobiferus* band is separated from the *Monograptus gregarius* zone by the intercalation of several feet of black grit and dark fossiliferous shale. The beds ranging from the *Monograptus gregarius* zone to the *Diplograptus acuminatus* zone appear less thick than in the typical Moffat sections, though reliable measurements are not easily obtained owing to the reduplication of the bands by folding. A portion of the *Dicellograptus anceps* zone is separated from the Birkhill Shales only by a very thin layer of sediment.

The greatest variation, however, is visible in the upper portion of the Hartfell group. About 180 feet of grits are intercalated with the Barren Mudstones. Thin bands of green shale with thin fossiliferous black shales are occasionally interleaved in the grits. In one of the thicker zones of shale, bands and nodules of limestone occur which may probably represent the Wrae Limestone of Peeblesshire. Some of the characteristic fossiliferous zones of the Lower Hartfell black shale have been recognised in these exposures.

The section extends for about three-quarters of a mile from the foot of the Baillie Burn, joining the Ettrick from the south, along the course of the river to the bend in that stream named

Gait Crook. If, for the moment, we eliminate the reversed and normal faults, the strata are arranged in an isoclinal fold trending north-east and south-west, the axis of which is inclined to the north-west, the strata dipping at angles varying from 25°–70°.

Lower Section from the Baillie Burn to the Cliff below the Manse in the River Ettrick.—Descending the Baillie Burn (Fig. 20), the brown crusted flags and shales (Abbotsford flags) are exposed on the east bank and in the bed of the stream dipping to the N.N.W. About 150 yards above the foot of the burn the angle of inclination is 50°, but as we descend it decreases to 15°. A few yards above the junction the jointed grey greywackes are succeeded by black cherts much jointed and exposed in the bed of the stream. The latter are not seen in contact with the greywackes, there being

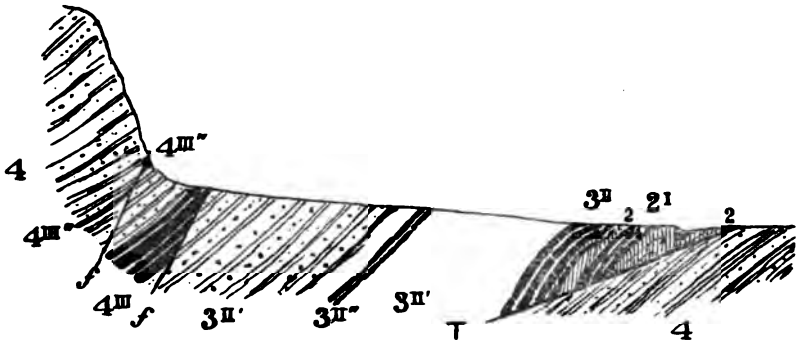


FIG. 20.—Section in River Ettrick from Manse Cliff to foot of Baillie Burn (No. 1 in Fig. 19).

2. Glenkiln chert. *(For further explanation, see Fig. 19.)*

a blank of a few feet in the section. Here, as we shall point out in the sequel, a reversed fault must intervene. Following the burn downwards the black cherts charged with radiolaria are well seen on the east bank, dipping down stream. About seven yards from the junction a band of black shales occurs, containing the following characteristic Glenkiln forms: *Dicranograptus minimus* (Lapw.), *Cœnograptus gracilis* (Hall), *Cryptograptus tricornis* (Carr.), and *Diplograptus*.

At the junction in the bed of the Ettrick, visible when the stream is low, the lowest zone of the Hartfell black shale is found, yielding specimens of *Climacograptus Wilsoni* and *Diplograptus foliaceus*. These bands are succeeded by a few feet of pale shales, followed by the main mass of the Hartfell black shales. At the foot of the Baillie Burn the cherts which extend down the Ettrick are truncated by a normal fault trending north-east, bringing in the Lower Hartfell black shale.

Westwards up the Ettrick, the Hartfell black shales are succeeded by 150 feet of shales, the lower portion resembling mudstones, and weathering with a cream colour, while the upper part is

more micaceous and of a green tint. In the lower bands there are two thin seams of black shale yielding large *Diplograpti:* in the upper portion are two thin layers of black shale, with *Dicellograptus anceps* (Nich.). These mudstones, dip to the N.N.W. at angles varying from 40° to 50°. Here they are followed by a mass of grey and black grits about 180 feet thick, pebbly in places and containing galls of black shale with intercalations of grey and black shales. At this point they are exposed on a cliff where a small reversed fault is seen; they can be examined to better advantage further up the river.

This arenaceous series is overlain by black shales, soft and friable, associated with dark blue shales yielding the following fossils: *Monograptus gregarius* (Lapw.), *M. tenuis* (Portl.), *M. attenuatus* (Hopk.), *Diplograptus confertus* (Nich.), *Climacograptus normalis* (Lapw.), and *Dawsonia campanulata* (Nich.). The flaggy black shales of the *D. vesiculosus* zone are not here represented. They occur further up the stream, and hence it is evident that a portion of the Lower Birkhill Shales has been thrown out by a fault (Fig. 20).

These black shales are overlain by a few feet of shales and greywackes, followed by blue shales with dark seams. In one of these thin seams the following assemblage of fossils was obtained under the Manse Cliff. From this list it is apparent that the band belongs to the horizon of *Rastrites maximus*, the specimens being remarkably well preserved:

Rastrites maximus (Carr.)
,, *capillaris* (Carr.)
Monograptus tenuis (Portl.)
,, *spiralis* (Geinitz.)
,, *Sedgwicki*, var. *spinigerus* (Nich.)
Monograptus Hisingeri (Carr.)
,, *lobiferus* (M'Coy.)
,, *priodon* (Bron.)
,, *attenuatus* (Hopk.)
Petalograptus folium (His.)
Diplograptus Hughesi (Nich.)

A small fault, amounting to a few feet in its displacement, brings down the overlying flaggy greywackes and shales (Abbotsford flags), and probably conceals part of the *Rastrites maximus* zone.

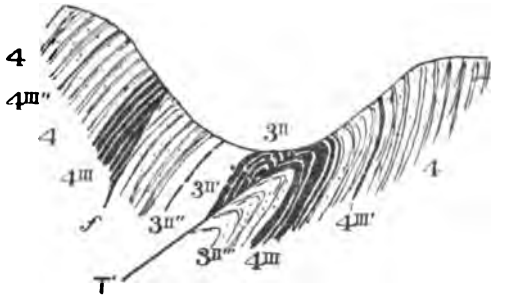


FIG. 21.—Section in River Ettrick at bend above Manse, Ettrickbridge-end. (No. 2 in Fig. 19).
(For further explanation, see Fig. 19.)

In ascending the river from the cliff below the Manse, where it takes a bend towards the south, we pass in descending order (1)

the Lower Birkhill black shales, (2) the grits with thin bands of dark shales yielding graptolites, (3) the green and grey shales representing the Barren Mudstones. Here the strata are thrown into a sharp anticlinal fold well seen on both banks of the stream. In the centre of this arch on the north side of the river a small exposure of black shales has yielded *Dicellograpti* belonging to the Hartfell group.

On the south bank, at this locality, the Lower Birkhill black shales (4^{III}) are seen forming an inverted anticline and apparently dipping below the Hartfell black shales (3^{II}), as shown in the accompanying section (Fig. 21).

The horizon of these black shales on the south bank is clearly proved by the following list of fossils obtained from them :

Diplograptus acuminatus (Nich.)
,, ,, showing radicles.
Climacograptus innotatus (Nich.)
,, *normalis* (Lapw.)
Monograptus gregarius (Lapw.)
Monograptus tenuis (Portl.)
,, *cyphus* (Lapw.)
Retiolites, sp.
Dawsonia campanulata (Nich.)

It is evident, therefore, that the Lower Hartfell black shales at this point have been made to overlie the Birkhill black shales by means of a reversed fault, probably the continuation of the dislocation which in the Baillie Burn truncates the inverted anticline.

As we advance up the river, we pass from the exposures of the Lower Birkhill beds to the greywackes and shales of the Tarannon series dipping towards the N.N.W. at an angle of 25°. On the cliff bounding the stream on the north side the flags and greywackes plunge underneath the Birkhill beds, so that here there may be the southern limb of an isoclinal fold.

On referring to the ground-plan (Fig. 19) it will be seen that about 300 yards up stream from the Manse Cliff a normal fault crosses the river with a downthrow to the west, by means of which the outcrop of the Birkhill beds has been shifted from the north to the south bank. At this point grey and blue shales are inclined to the north-west at 30°, yielding *Rastrites capillaris* (Carr.), *Monograptus tenuis* (Portl.), &c. Underneath lies an inverted arch of the lower zones of the Birkhill Shales, which extends up the south bank. The river cuts obliquely across this isocline, which continues up the stream for a distance of about 200 yards. The fold widens so as to expose the band yielding *Dicellograptus anceps* (Nich.) and *Diplograptus truncatus* (Lapw.) But soon the arch is truncated by a normal fault, which, crossing the river, brings the Hartfell black shales into contact with the Lower Birkhill beds.

For 250 yards up the stream the Lower Hartfell black shales are "stepped" downwards to the west by six small normal faults (Fig. 19). Further, these beds have been driven over each other by reversed faults well seen on the right bank at the bend of the stream nearly opposite Kirkhope Farmhouse. The Barren Mudstones

are seen in the bed of the river, occupying their normal position above the Lower Hartfell black shales.

But on the cliff that forms the north bank of the river along this part of its course, the Llandovery greywackes and shales succeed, dipping towards the N.N.W. at angles varying from 20° to 30°. Their horizon is clearly defined by the occurrence of thin dark seams near the foot of the cliff yielding *Rastrites maximus* (Carr.) and *Monograptus Sedgwicki*. This zone is there interleaved in the grey shales and greywacke ribs (Abbotsford flags), the cleavage of the shales between the greywackes being at a higher angle than the dip of the beds. It is clear, therefore, that a fault must here intervene between the Barren Mudstones and the *Rastrites maximus* zone (Fig. 22).

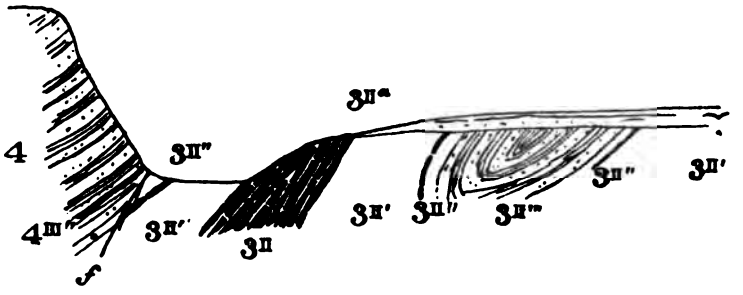


FIG. 22.—Section across River Ettrick, southwards from Kirkhope Farm (No. 3 in Fig. 19).

~ Recent alluvium. *(For further explanation, see Fig. 19).*

At the bend in the river above Kirkhope Farmhouse, the Glenkiln cherts are exposed in the bed of the stream, in the strike of the fold referred to, showing the Lower Hartfell black shales. On the north side of the cherts, and on the left bank, hardened black shales succeed, yielding *Diplograptus foliaceus* (Murch.), *Dicellograptus Morrisi* (Hopk.), *Climacograptus*, &c., and thus indicating a Lower Hartfell horizon.

Upper Section from the Bend above Kirkhope Farmhouse to Gait Crook.—From the bend above Kirkhope Farmhouse to Gait Crook, an interesting sequence is met with. There the course of the river is nearly north and south, and a transverse section of the strata is displayed. Their stratigraphical relations are disturbed by several normal faults exposed in the bed of the stream, but the general order of succession can be pretty clearly established (Fig. 23).

Beginning with the anticline of the Lower Hartfell black shales seen at the band near Kirkhope Farmhouse, we find their position to be clearly proved by the following list of fossils:

Pleurograptus linearis (Carr.)
Leptograptus flaccidus (Hall.)
,, *capillaris* (Carr.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Dicellograptus Forchhammeri (Geinitz.)
,, *moffatensis* (Carr.)
Climacograptus, sp.
Siphonotreta micula (M'Coy.)

Southwards along the east bank there is a clear exposure of grey and purple shales representing the Barren Mudstones, with occasional bands of grey greywacke and grit. These beds are inverted and dip to the N.N.W. Next in order come dark grits and shales, with black shale bands, probably on the same horizon as the grits already described in the Hartfell group below the Manse.

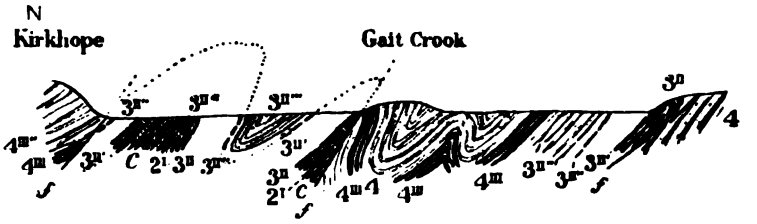


Fig. 23.—Section in River Ettrick from bend above Kirkhope, through the Gait Crook (No. 4 in Fig. 19).

(For further explanation, see Fig. 19.)

Further southwards grey shales appear together with a black shale band yielding *Diplograptus truncatus* (Lapw.)

Further south this horizon is followed by grey shales with nodules and ribs of limestone, till another exposure of Lower Hartfell shales is met with, yielding *Pleurograptus linearis* (Carr.), *Leptograptus capillaris* (Carr.). *Diplograptus foliaceus* (Murch.), *Cryptograptus tricornis* (Carr.), *Retiolites (Neurograptus) fibratus*, &c. By means of a fault this band is brought into conjunction with the zone of *Dicellograptus anceps* (Nich.) on the south side of the outcrop. The latter horizon has also yielded *Diplograptus truncatus* (Lapw.)

Owing to faulting, the Lower Birkhill black shales are not satisfactorily exposed on the east bank, but on the opposite side of the stream they are seen to advantage on a cliff rising from the river channel. From the latter locality the following forms have been obtained:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *Hisingeri* (Carr.)
Climacograptus normalis (Lapw.)
Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
,, *confertus* (Nich.)

Towards the south they are succeeded on the west bank by grey greywacke bands with grey silky shale partings, which dip towards the north at high angles.

Returning to the east bank of the stream and crossing the bands of black shales that represent the Lower Birkhill zones, we find on the south side black grits and barren shales which are abruptly truncated by a fault. Next in order a few feet of black grit are followed by grey shales with dark streaks and about six feet of dark shale, the lower portion of which yields fossils

belonging to the upper part of the *Monograptus gregarius* zone. To these beds succeed the Abbotsford flags, occupying the stream section to Gait Crook.

On the south side of the loop at Gait Crook the foregoing flags and shales form an inverted arch. From this point to the bank on the south side of the bend of the river there is a blank in the section. But at the latter locality, near a cottage, black shales, much corrugated and shattered, have yielded the following characteristic Hartfell forms (Figs. 19, 23):

Dicellograptus Morrisi (Hopk.)
,, like *anceps* (Nich.)
,, *elegans* (Carr.)
Leptograptus flaccidus (Hall.)
Climacograptus bicornis (Hall.)
Diplograptus foliaceus (Murch.)
,, *truncatus* (Lapw.)
Siphonotreta micula (M'Coy.)

The relations of this outcrop to the surrounding strata are completely obscured; but it is highly probable that the Hartfell black shales come to the surface along another anticline to the south of the main fold at Ettrickbridge-end. If this be so, then in the alluvial flat at Gait Crook it is probable that the Abbotsford flags may be thrown into a synclinal fold underlain by the Lower Birkhill Shales (Fig. 23).

Returning now to the section in the river below the junction of the Baillie Burn, we may observe that the Abbotsford flags and shales occupy the stream down to a point below where it is joined by Jean's Burn from the west. From the latter locality, for a distance of 300 yards, no rocks are visible; but at the bend below Woodend, the Barren Mudstones, with a band of black shales and the black grits, are found. Near the foot of the Brockhill Burn the black shales of the Birkhill division are associated with black grits. The section is much disturbed and broken by faults.

If we review the evidence now adduced regarding the physical relations of the strata in the Ettrickbridge-end section, it is clear that originally the representatives of the Moffat series must have been arranged in one great isoclinal fold inclined to the north-west at a very gentle angle, extending from the foot of the Baillie Burn to the bend above Kirkhope Farmhouse. The isolated outcrop of Hartfell shales south of Gait Crook probably indicates a minor fold to the south of the main anticline.

At the foot of the Baillie Burn, however, the southern inverted limb of the main anticline has been removed by a reversed fault, and hence the radiolarian cherts in the Glenkiln group appear to overlie the Abbotsford flags. The horizon of the latter is clearly defined in other parts of the section by the intercalation of the *Rastrites maximus* bands.

The outcrop of this reversed fault or thrust-plane seems to cross the river Ettrick at the bend above the Manse Cliff, where the Lower Hartfell black shales appear to overlie the Lower Birkhill Shales. The natural order of the strata is further disturbed by a series of normal faults with a general downthrow to the west.

Singlee Burn.—On the north side of the valley of the Ettrick, and about a mile up stream from the arch of the Moffat series at Ettrickbridge-end, black shales again appear in the Singlee Burn, which yield forms characteristic of the Hartfell and Birkhill divisions.

CHAPTER VII.

THE CENTRAL BELT—*continued.*

BLACK SHALE BANDS NORTH OF MOFFATDALE.

Proceeding now to the region lying between the Moffat Water and the northern margin of the Tarannon area beyond the vale of Tweed, we shall describe the successive anticlines of the Moffat Shales within these limits, and indicate the lateral variation of the sediments as we approach the Abington and Leadhills districts.

Polmoody.—In the basin of the Moffat Water there are several local anticlines of the Moffat Shales. A glance at Sheet 16 will show that one of these folds has been traced from the Tail Burn issuing from Loch Skene to a small stream about a mile north-east of Polmoody. The Birkhill Shales are exposed in this outcrop, and in the Seary Sike, joining the Polmoody Burn from the slopes of the Turnberry Hills, the Barren Mudstones form the crest of the arch, with the crushed and contorted Birkhill zones on either side.

Carrifran Burn (Lower Section).—A small anticline occurs near the foot of this stream revealing only the Birkhill zones. Owing to the decomposition of the strata, the stream follows the crest of the fold for a short distance.

Bodesbeck.—In like manner, this minor fold shows only Birkhill Shales charged with *Monograptus Sedgwicki* (Portl.), *Monograptus lobiferus* (M'Coy), *Climacograptus normalis* (Lapw.), *Diplograptus tamariscus* (Nich.).

Roundstonefoot and Shortwoodend.—Here two small isoclinal folds of the Birkhill shales occur in the midst of the Tarannon grits; the exposure near the foot of Shortwoodend Burn has yielded *Monograptus Hisingeri* (Carr.), *Monograptus lobiferus* (M'Coy), *M. leptotheca* (Lapw.), *M. gregarius* (Lapw.), *Diplograptus tamariscus* (Nich.), *Climacograptus normalis* (Lapw.).

Frenchland Burn.—Two separate exposures of the Moffat series occur in this stream; the intervening area, about a quarter of a mile in extent, being occupied by the Tarannon greywackes and shales. In the lower section the black shales are overlapped by the Permian rocks, and may be traced up stream for a quarter of a mile. They are arranged in sharp isoclinal folds dipping to the north-west. The strata being much corrugated, fossils are not easily obtained from all the zones. but those which can be found clearly belong to the Birkhill division, The lowest zone, as described by Professor Lapworth, yields *Diplograptus vesiculosus*, passing upwards into the higher beds, which in

turn plunge underneath the greywackes and shales to the south. At the upper limit of this exposure the higher bands yield, in fine preservation, *Monograptus Sedgwicki, M. Becki, M. Hisingeri.*

In the upper exposure the strata are similarly arranged, being isoclinally folded towards the north-west. Here the zones range from the base of the Birkhill division to the members of the upper group. At the south-west limit the strata belonging to the Lower Birkhill division are truncated by a fault bringing in the overlying greywackes and shales. Further up the stream higher zones succeed, but the junction of the latter with the greywackes is not visible. The following fossils have been obtained from these beds:

Monograptus Sedgwicki (Portl.)
,, *leptotheca* (Lapw.)
,, *lobiferus* (M'Coy.)
,, *gregarius* (Lapw.)
Petalograptus folium (His.)
Climacograptus scalaris (His.)
Climacograptus normalis (Lapw.)
Dimorphograptus elongatus (Lapw.)
Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
,, *tamariscus* (Nich.)

Garpol Water.—The relations of the Moffat Shales to the Tarannon greywackes are clearly displayed in this stream, which lies to the west of the river Annan, and is about a mile and a half distant from the town of Moffat. Here a gorge has been carved out of the softer shales between the overlying grits and greywackes. The strata are arranged in a compound anticline traversed in the centre by a small fault, as shown by Professor Lapworth. The lowest beds exposed in the centre of the arch belong to the *Diplograptus acuminatus* zone of the Lower Birkhill Shales, which have yielded the following fossils:

Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus Swanstoni (Lapw.)
Climacograptus normalis (Lapw.)
Climacograptus innotatus (Nich.)
Monograptus attenuatus (Hopk.)
,, *tenuis* (Portl.)
Dawsonia campanulata (Nich.)

Below the waterfall near the bend in the stream higher bands are well seen, in particular the *Monograptus gregarius* zone, containing nodules of limestone as in the Dobb's Linn section. Some of these nodules are several feet in diameter. This exposure occurs on the north limb of the anticline as the observer ascends the stream. Though the bands are there much disturbed they are highly fossiliferous, and have yielded the following fossils, some of which are preserved in the solid:

Monograptus gregarius (Lapw.)
,, *cyphus* (Lapw.)
,, *leptotheca* (Lapw.)
,, *lobiferus* (M'Coy.)
,, *triangulatus* (Hark.)
,, *tenuis* (Portl.)
Diplograptus with ovarian capsules.
,, *tamariscus* (Nich.)
Diplograptus physophora (Nich.)
Petalograptus folium (His.)
Climacograptus innotatus (Nich.)
Rastrites peregrinus (Barr.)
Discinocaris Browniana (Woodw.)
Theca (?)
Crustacean.

Above the bend in the stream where its course is nearly north and south, the beds, chiefly of the Upper Birkhill division, are

exposed in transverse section, plunging on both sides under the Tarannon greywackes. Here the grey and black shales of the *Monograptus spinigerus* zone are met with, yielding that form in profusion, together with specimens of *Monograptus runcinatus* (Lapw.), *M. leptotheca* (Lapw.), *M. Hisingeri* (Carr.), *Rastrites hybridus* (Lapw.), *Petalograptus folium* (His.), *Diplograptus tamariscus* (Nich.), *Climacograptus*, &c. On the north limb of the fold the purple shales of the *Rastrites maximus* zone, which have here failed to yield their characteristic fossils, dip below the overlying greywackes. The same zone on the south limb of the fold has yielded a few characteristic forms.

Carrifran Gans and Blackhope Burn.—From the slope of White Coomb a band can be traced for about three miles across the Carrifran Burn to Blackhope Burn, along a line about a mile and a half to the north of the course of the Moffat Water. In the Broomy Gutter, draining the north slope of Carrifran Gans and flowing into the Carrifran Burn, the following section occurs not far above the junction of the stream:

In the centre of the inverted anticline the Hartfell black shales are exposed, to which succeed the Barren Mudstones. To the south these are overlain by the Lower Birkhill black shales, while on the north limb the Barren Mudstones are truncated by a fault bringing in the greywackes and shales.

At the junction of the two streams the fold widens and reveals the underlying Glenkiln black shales, yielding the following characteristic forms:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *nitidulus* (?) (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Climacograptus cœlatus, var. *antiquus* (Lapw.)
Climacograptus bicornis (Hall.)
Dicellograptus sextans (Hall.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Acrotreta Nicholsoni (Dav.)

Further up the small "score" the Barren Mudstones appear in the centre of the fold overlain by the Birkhill Shales, the southern limb being truncated by a fault.

Again, where this fold occurs in a "score" on the east side of the Blackhope Burn, only the Birkhill Shales are met with, but overlying these beds are green and grey shales which may represent part of the Upper Birkhill strata.

Birnock Water.—The probable continuation of the foregoing band occurs in the Birnock Water about a mile and a half to the north-east of Moffat. There the beds are much shattered, and it is difficult to procure determinable fossils. The Birkhill Shales, Barren Mudstones, and a portion of the Hartfell black shales are met with. This outcrop is of interest as being the site of one of the mineral wells which have made the town of Moffat a favourite resort.

Blackhope Burn (Foot of Whirly Gill).—Immediately below the junction of these two streams an exposure of black shales yields Lower Birkhill forms in the heart of a mass of grey shales

like those associated with dark bands yielding *Rastrites maximus* at Dobb's Linn. Here there are indications of the disappearance of the upper portion of the Birkhill group. Indeed, between the foregoing outcrop and that at the head of the Cold Grain—one of the sources of Blackhope Burn—there are several folds of these grey shales in the midst of the Tarannon grits.

Hartfell Section.—Reference has already been made to the fact that Professor Lapworth has proved the disappearance of the upper portion of the Birkhill division on the great anticline of Hartfell. Indeed, in most of the arches of the Moffat Shales on the strike of the Hartfell band, this modification of the Upper Birkhill division is more or less apparent. On referring to Sheet 16 of the one-inch geological map of Scotland, it will be seen that black shale bands in the line of the Hartfell arch can be followed at intervals from the south-west border of the map, north-east by Ruttonside, Hartfell, and Loch Skene, to Boar Cleuch in the basin of the Meggat Water. North of this line the Upper Birkhill beds, as developed in Dobb's Linn, are never met with on any of the anticlines of black shales. It is clear, therefore, that the Hartfell arch forms an important structural line in relation to the lateral variation of the lithological and palæontological zones of the Moffat series.

The Hartfell section, extending for a distance of three miles from the edge of the Permian basin to the summit of that mountain, has been described in detail, and the horizons of the various palæontological zones have been indicated by Professor Lapworth. The strata generally are arranged in the form of a compound anticline, traversed by faults more or less parallel to the strike of the strata, the lowest zones being exposed in the fine section in the Hartfell "Score."

Not far from the margin of the Permian basin, in the Frizzle Burn, the black shales and mudstones of the *Monograptus gregarius* zone pass conformably upwards into the massive grits of Tarannon age without any representative of the Upper Birkhill Shales. The same strata reappear at the old copper mine, further up stream, where they have yielded the following forms:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *leptotheca* (Lapw.)
,, *triangulatus* (Hark.)
,, *lobiferus* (M'Coy.)
Diplograptus tamariscus (Nich.
Petalograptus folium (His.)
Rastrites peregrinus (Barr.)
Dawsonia campanulata (Nich.)

About 300 yards above the old mine another exposure of the *M. gregarius* zone occurs, from which the following fossils have been obtained:

Monograptus gregarius (Lapw.)
,, *lobiferus* (M'Coy.)
,, *leptotheca* (Lapw.)
,, *triangulatus* (Hark.)
,, *Sandersoni* (Lapw.)
,, *spiralis* (Geinitz.)
Monograptus communis (Lapw.)
Rastrites peregrinus (Barr.)
Diplograptus tamariscus (Nich.)
Climacograptus rectangularis (M'Coy.)
Dawsonia campanulata (Nich.)
Discinocaris browniana (Woodw.)

The section in Hartfell "Score" at the head of the glen, as shown by Professor Lapworth (Quart. Jour. Geol. Soc., vol. xxxiv., p. 295), displays on a large scale the various sub-divisions of the Lower Hartfell black shales. From this locality the Hartfell division of the Moffat series takes its name (Fig. 24).

The axis of the main anticline runs parallel to the stream draining the "Score" above the Spa Well, the crest of which coincides with a fault, probably reversed, that truncates the Birkhill Shales on the south side of the stream and brings them in contact with Glenkiln and Hartfell strata to the north.

Taking first the south limb of the main arch, which lies to the south of the fault just referred to, the observer finds a minor fold revealing the Hartfell black shales below the Spa Well, the lowest beds belonging to the *Dicranograptus Clingani* zone. The Barren Mudstones ($3^{III'}$ in section) follow in regular order to the north-west and south-east, folding round the underlying beds. They are likewise traceable for a short distance along the slope on the south side of the "Score," where they are associated with a band of highly decomposed volcanic breccia.

At the Spa Well the Lower Birkhill Shales (4^{III} in section) appear to the north of the outcrop of Barren Mudstones, where they have yielded the following forms:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *cyphus* (Lapw.)
,, *attenuatus* (Hopk.)
Diplograptus vesiculosus (Nich.)
,, *tamariscus* (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus elongatus (Lapw.)

The foregoing outcrop of Birkhill Shales, though in a somewhat shattered condition, can be traced along the south side of the gorge to the head of the "Score." Along the top of the south cliff the Tarannon grits and shales may be followed, where for some distance they pass down conformably into the *Monograptus gregarius* bands of the Lower Birkhill division.

Turning now to the great crag on the north side of Hartfell "Score" (Fig. 24), the observer encounters a broad development of black shales, extending high up the mountain, which is due to the sharp reduplication of the Lower Hartfell black shales (3^{II} in section) and the underlying mudstones, cherts, and black shales belonging to the Glenkiln group (2^{c} in section). Indeed, the alternation of bands of orange-coloured mudstones and cherts with black shales forms a striking feature of the lower portion of the scar.

Before describing the relations of these mudstones and cherts to the Hartfell black shales, we may refer to certain lavas and volcanic tuffs, which, from their associated fossils, are probably of Llandeilo age. They occur in the stream and on the adjoining slope to the north-east, at a point about 250 yards up the burn from the Spa Well. On the south side the volcanic rocks are truncated by the main fault in the Hartfell "Score," which brings them in contact with the Birkhill Shales on the

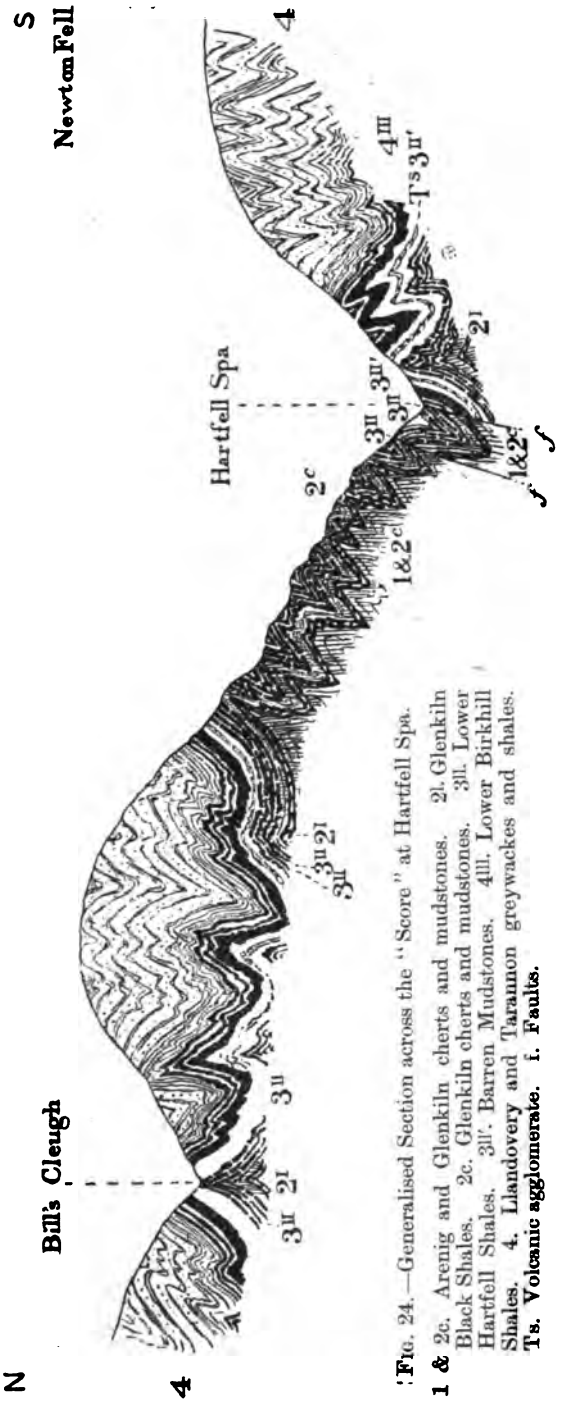


FIG. 24.—Generalised Section across the "Score" at Hartfell Spa.

1 & 2c. Arenig and Glenkiln cherts and mudstones. 2l. Glenkiln Black Shales. 2c. Glenkiln cherts and mudstones. 3ll. Lower Hartfell Shales. 3ll'. Barren Mudstones. 4lll. Lower Birkhill Shales. **4. Llandovery** and Tarannon greywackes and shales. **Ts. Volcanic agglomerate. f. Faults.**

south limb of the main arch; while on the north side they are cut off by a fault which places them in conjunction with Hartfell Shales. It will thus be seen that their horizon cannot be satisfactorily determined from their stratigraphical relations. The volcanic tuff, which is visible on the right bank of the burn below the forkings, is only a few feet broad, and on the north side of this exposure, where it is faulted against the Hartfell black shales, it contains a thin streak of fossiliferous black shale. On the slope to the north-east, and only a few yards from the burn, there is a small boss of lava and volcanic tuff, which is clearly the prolongation of the band in the stream. A specimen of the lava (7161), examined by Mr. Teall, has been termed diabase-porphyrite, too much altered for precise determination. Here also, on the north side of the exposure, fossiliferous black shale appears, which is interleaved in the tuff. From the latter outcrop, as well as from the seam of dark shales in the ash in the stream, the following forms have been obtained, which have been kindly determined by Professor Lapworth:

Didymograptus superstes (Lapw.)
Leptograptus magnus (Lapw. ?)
Dicellograptus patulosus (Lapw.)
Climacograptus bicornis (Hall.)
Climacograptus cælatus var. *antiquus* (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Lasiograptus Harknessi (Nich.)

A few yards to the north of the exposures of volcanic rocks and associated graptolite shales, the orange-coloured mudstones and cherts are visible at the forkings of the burn, where they occur along two isoclines overlain by the Hartfell black shales. Not far to the north-west of the forkings, on the north side of the northmost arch of these mudstones, their junction with the overlying black shales is well seen. Here, at the base of the Lower Hartfell division, occurs the *Climacograptus Wilsoni* zone, composed of grey flinty mudstone and dark shales, where specimens of that zonal form are associated with *Buthograptus laxus*, *Climacograptus bicornis*, *Glossograptus Hincksi*, &c. This zone is underlain by two feet of black shales, with seams of volcanic ash half an inch thick; the latter resting directly on the orange-coloured mudstones, and yielding in profusion the following assemblage of forms: *Dicranograptus zic-zac*, *D. ramosus*, *Cœnograptus pertenuis*, *Climacograptus Schärenbergi*, *Corynoides calycularis*, Of these species the first three occur on one slab from a seam about six inches above the top of the orange-coloured mudstones. It is probable, therefore, that this thin band of black shale between the *C. Wilsoni* zone and the top of the mudstones may represent the highest sub-zone of the Glenkiln shales, as in Dobb's Linn and Craigmichan Scaurs.

This view of the correlation of these mudstones and overlying black shales is strengthened by evidence obtained from another exposure on the same crag to the north of the Spa Well. Owing to the scree material it is difficult to fix the spot from which the fossils in the following list were collected; but the band underlies

the *Climacograptus Wilsoni* zone with *Buthograptus laxus*, and overlies the orange-coloured mudstones and cherts with radiolaria:

Dicranograptus zic-zac (Lapw.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
,, *formosus* (Hopk.)
Thamnograptus scoticus (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus peltifer (Lapw.)
Diplograptus foliaceus (Murch.)
,, *angustifolius* (Hall.)
Lasiograptus bimucronatus (Nich.)
Glossograptus Hincksi (Hopk.)
Clathrograptus cuneiformis (Lapw.)

Proceeding now to the sub-zones of the Hartfell black shales overlying these orange-coloured mudstones, the observer can trace them along the face of the north crag, where they are much contorted and thrown into parallel folds. The bands of the *Climacograptus Wilsoni* zone have yielded at various points along their line of outcrop the following fossils:

Climacograptus Wilsoni (Lapw.)
,, *bicornis* (Hall.)
,, *Schärenbergi* (Lapw.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
Corymoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

Next in order occurs the zone of *Dicranograptus Clingani*, consisting of flaggy black shales, which may be studied to advantage in the fine exposures on the north side of the "Score," where the forms given in the annexed list were collected:

Dicranograptus Clingani (Carr.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
Dicellograptus Forchhammeri (Geinitz.)
,, *caduceus* (Lapw.)
,, *elegans* (Carr.)
Leptograptus flaccidus (Hall.)
Climacograptus caudatus (Lapw.)
Diplograptus foliaceus (Murch.)
,, *truncatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Discina, sp.
Acrotreta, sp.

To these succeed the slaty black shales of the *Pleurograptus linearis* zone, from which the following forms have been collected:

Pleurograptus linearis (Carr.)
Leptograptus flaccidus (Hall.)
,, *capillaris* (Carr.)
Diplograptus quadrimucronatus (Hall.)
,, *foliaceus* (Murch.)
Retiolites (Neurograptus) fibratus (Lapw.)
Dicellograptus elegans (Carr.)
,, *Morrisi* (Hopk.)
Amphigraptus divergens (Hall.)
Climacograptus bicornis (Hall.)
,, *tubuliferus* (Lapw.)
Corymoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

So highly convoluted are the strata on the north cliff that it is almost impossible to determine definitely the extent of the reduplication of the zones; but at the extreme north-eastern corner of the "Score" the *Climacograptus Wilsoni* zone reappears, where it yields specimens of *Buthograptus laxus*, and is followed towards the north by the orange-coloured mudstones of the Glenkiln division.

The crest of the ridge north-west of Hartfell "Score" is occupied by grits and shales (Tarannon), but the Moffat Shales come to

the surface on another anticline in Bill's Cleugh (Fig. 24) parallel to that of Hartfell. There the lowest visible strata consist of Barren Mudstones, which are followed by black shales yielding Lower Birkhill graptolites.

About half a mile to the north-east—in Pot Burn—the prolongation of the Hartfell band is met with, where Lower Birkhill strata are exposed, and again at the head of Cold Grain, below the summit of Hartfell. At the latter locality the black shale bands present an interesting palæontological feature, for there the *Monograptus spinigerus* zone occurs with the *M. gregarius* zone, thus showing that at the north-east termination of this anticline a portion of the Upper Birkhill division is still to be found. The following forms have been collected from this exposure: *Monograptus spinigerus* (Nich.), *M. Hisingeri* (Carr.), *M. lobiferus* (M'Coy), *M. gregarius* (Lapw.), *M. attenuatus* (Hopk.), *M. spiralis* (Geinitz), *M. tenuis* (Portl.), *Climacograptus normalis* (Lapw.).

Ruttonside.—Taking now the bands more or less in the strike of Hartfell to the west of the Permian basin, the observer finds a similar absence of the fossiliferous zones of the Upper Birkhill division. At Ruttonside, in the railway cutting, there are two anticlines of black shales embedded in grits and greywackes. They yield *Diplograptus vesiculosus* (Nich.), *Monograptus gregarius* (Lapw.), *Climacograptus normalis* (Lapw.), &c. These beds are followed rapidly by greywackes, with only thin flags and shales intervening. The same features are observable in the Cloffin Burn about a mile to the south-west of Ruttonside.

Headshaw Linn.—About a mile north of Ruttonside, in the Headshaw Linn, Dead Burn, a small but clear section is found. The lower part of the burn is occupied by greywackes and shales dipping towards the north-west at an angle of about 30°. On crossing a line of fault trending north-west, with a downthrow to the west, members of the Moffat series are exposed in an isoclinal fold. Here they consist of beds belonging to the *Monograptus gregarius* zone and the *Diplograptus vesiculosus* zone. At one point the Barren Mudstones emerge from beneath thin black shale bands. All the strata are very much decomposed, the *Diplograptus vesiculosus* band being even bleached into a lilac-coloured clay. The following among other forms were obtained: *Monograptus gregarius* (Lapw.), *M. triangulatus* (Hark.), *M. cyphus* (Lapw.), *Rastrites peregrinus* (Barr.), *Petalograptus folium* (His.), *Diplograptus tamariscus* (Nich.).

To the north and south of this fold a few feet of purple barren shales succeed, and these are followed by the greywackes and shales (Queensberry grits) of Llandovery-Tarannon age.

Gameshope Burn.—Further to the north-east of Hartfell there are three small local folds in the streams draining into this burn near the water-shed. In the west branch, about two miles north-east of Hartfell, black shales that have bleached white occur, in which *Climacograptus normalis* (Lapw.) was found. Grey shales are associated with the foregoing bands, and in the north side

of the fold they plunge underneath the greywackes and grits at angles varying from 40° to 50°.

In another branch of the Gameshope Burn, north of the watershed at Loch Skene, bands belonging to the *Monograptus gregarius* zone occur, yielding also *M. leptotheca* (Lapw.), *Diplograptus tamariscus* (Nich.). These are immediately overlain by shales, flags, and greywackes.

Mid Craig, Loch Skene.—In a notch on the Mid Craig overlooking Loch Skene, on the west side, a band appears of Moffat Shales, which can be traced for about two miles. The Barren Mudstones occupy the centre of the fold, followed on both sides by the Lower Birkhill black shales, with their characteristic fossils, especially those of the *Monograptus gregarius* zone. These are overlain by a limited thickness of grey shales, probably representing part, if not the whole, of the upper portion of this division. At the head of the "Score" the inverted anticline is abruptly narrowed by two branching faults with a downthrow to the west. Of these the northern one is the more powerful, as it brings the greywackes and grits into contact with the black shales, while the southern one throws the grey shales against the fossiliferous bands.

To the west of the faults the anticline does not show the Barren Mudstones, but only the overlying black shales.

A short distance to the south of the foregoing arch, in a notch on the Mid Craig opposite the middle of Loch Skene, a black sandy bed occurs among the Tarannon grits. It is about three feet wide, with a few inches of shaly clay containing indistinct traces of graptolites. Here occur nodular masses of crystalline limestone and spathic iron-ore, the latter decomposing into brown oxide of iron.

Immediately to the south of the anticline of the Moffat Shales on the Mid Craig there is a broad exposure of grey slaty shales, which are evidently repeated by numerous folds. They may probably represent the series immediately overlying the Birkhill beds.

The band at the head of Loch Skene reappears on the slopes of Lochcraig Head at a height of 2000ft., rising from underneath the Queensberry grits. Here, as on the Mid Craig just referred to, there is a greater breadth of the barren grey shales on the south than on the north side of the fold.

Garlie's Cleuch, Winterhope.—On the other side of the watershed the same band is met with again in the streamlets flowing into Garlie's Cleuch, a tributary of the Meggat Water, where there are several flat anticlines of the Lower Birkhill beds associated with barren grey shales. Here a band of pebbly grit, interleaved in the latter strata, may probably lie on the same horizon as the pebbly band that occurs in the shales to the north-east.

From the occurrence of these local folds of the Moffat Shales in Garlie's Cleuch and the ridge to the south, within no great distance of each other, and in the strike of the strata in Mid Craig,

Loch Skene, it is probable that the Moffat Shales lie near the surface in several of the folds of grey shale at the latter locality.

Towards the north-east, black shales again appear on the hill-slope east of the great bend in Winterhope Burn, yielding *Diplograptus vesiculosus* (Nich.) and *D. acuminatus* (Nich.).

Shielhope, Syart Law, and Craigierig.—In the basin of the Meggat Water a band is traceable from the burn at Shielhope by Syart Law to the stream at Craigierig. Of the sections there exposed, one in the scar opposite Cramalt, on the slope of Syart Law, shows the greatest development of this series.

The Barren Mudstones are seen at the top of the scar, with the Lower Hartfell black shales rising from underneath, but here inverted. The latter are repeated by numerous isoclinal folds. They contain *Diplograptus foliaceus* (Murch.), *Dicranograptus ramosus* (Hall), *Dicellograptus Forchhammeri* (Geinitz).

The Barren Mudstones lie in some of the small synclines, but eventually they dip to the north-west and pass underneath the Lower Birkhill Shales and the overlying grey shales.

In the Shielhope Burn two small folds of the Lower Birkhill group may be seen. Again, in the burn at Craigierig, on the north bank of the Meggat Water, a very small exposure of the highest bands of the lower division of this group has yielded *Monograptus lobiferus* (M'Coy), *Diplograptus tamariscus* (Nich.), *Rastrites peregrinus* (Barr.). These strata are overlain by shales and pebbly grits, with fine silky shales like those with *Monograptus Sedgwicki* in Dobb's Linn. Some of the pebbly grits contain fragments of black shales.

Boar Cleuch, Glengaber Burn.—A beautiful normal anticline, as described by Professor Lapworth, occurs in this stream, and shows the infraposition of the Moffat series to the Queensberry grits. The Yair Burn is here deflected into the Boar Cleuch along the crest of the arch in the black shales. The flaggy black shales of the *Diplograptus vesiculosus* zone are exposed in the bed of the stream, being the lowest visible strata, followed by the bands representing the *Monograptus gregarius* zone. These are in turn overlain by a considerable thickness of grey flaggy shales underlying the grits. They are not fossiliferous, but it is highly probable that they represent the upper portion of the Birkhill division in Dobb's Linn.

Proceeding northwards, either along the course of the Glengaber Burn, or by the road from Craigierig towards the head of the Manor Water, we encounter several folds in the overlying Queensberry grit series, which bring up the dark grey shales associated with the Lower Birkhill beds in that region.

Dryhope Hope, Kirkstead Burn.—About a mile and a half to the north-east of the folds in Glengaber Burn and Boar Cleuch, similar evidence is obtained of change in the lithological characters of the members of the Birkhill division. For in the Kirkstead Burn, west of Dryhope Hope, there is a constant

repetition of blue-grey shales with thin grits, containing at one or two localities thin black seams, which enclose graptolites of the Upper Birkhill division. About one-third of a mile west of the shepherd's house of Dryhope Hope a thin dark seam in highly inclined grey shales furnishes specimens of *Monograptus spinigerus.*

Douglas Burn.—Crossing the watershed to the basin of the Douglas Burn, which joins the Yarrow about a mile and a half to the east of St. Mary's Loch, we find in several tributaries of this stream, near Muttonhole, exposures of representatives of the Moffat series. On the south slope of Jeffrey Rig, about half a mile to the west of Muttonhole, black shales and cherts, and black shales with white clays, are visible in small scars.

Slate Cleuch, Douglas Burn.—Further to the north-east, in the Slate Cleuch, that unites with the Douglas Burn at Muttonhole, members of the Glenkiln and Birkhill divisions appear in a highly disturbed condition on the south-west bank about 700 yards up the stream.

Beginning at the north-west limit of the section, the observer finds grey sandy shales dipping towards the north-west at 30°, which are faulted against a mass of black shales with black cherts, representing the Glenkiln group. The beds are much shattered, but the following forms were here obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus formosus (Hopk.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus, sp.

These Glenkiln Shales are followed to the south-east by cherts and mudstones which may represent part of the radiolarian cherts of Arenig age, succeeded by a second band of black shales yielding *Cryptograptus tricornis*, *Climacograptus bicornis*, &c. The latter are followed by mudstones and black sandy shales, containing fossils, belonging to the Birkhill group, viz.: *Rastrites maximus*, *Diplograptus tamariscus*, *Monograptus tenuis*, &c. It is evident that a fault separates these Birkhill strata from the representatives of the Glenkiln division.

On both sides of this exposure of the Moffat series there is a development of grey slaty shales with occasional flaggy grit bands; these are associated, on the north-west side of the fold, with a peculiar series of white or cream-coloured flinty shales, resembling the flinty bands in Earnscleuch, Lauderdale (see p. 197).

Black Cleuch, Douglas Burn.—High up on the western slope of the watershed that separates the Douglas Burn from Traquair Water, another section reveals representatives of the Glenkiln, Hartfell, and Birkhill divisions. It is exposed in a scar at the head of a rivulet draining into Black Cleuch, about a mile and a half up from its junction with the Douglas Burn, and about half a mile south of the crest of Dun Rig (2433ft.). Ascending this streamlet, the observer finds greywackes and shales,

nearly vertical or dipping to the north-west, followed by black shales. Along their south side the Moffat Shales are truncated by a fault that brings them in contact with the greywackes. Black flinty bands are associated with the black shales near the fault. From the following list of fossils obtained from these shales, it is evident that they represent the Glenkiln-Hartfell group, viz.: *Climacograptus peltifer*, *C. cælatus* var. *antiguus*, *C. Schärenbergi*, *C. caudatus*, *Dicranograptus ramosus*, *Dicellograptus*, *Cryptograptus tricornis*, *Diplograptus foliaceus*, *Corynoides calycularis*.

These strata are truncated by a fault which brings them into conjunction with blue-black sandy shales and clays of the *Monograptus gregarius* zone of the Lower Birkhill division. They present the following assemblage of graptolites: *Monograptus gregarius*, *M. lobiferus*, *M. triangulatus*, *M. leptotheca*, *M. tenuis*, *M. attenuatus*, &c. On the north side there is a passage upwards into greywackes and shales, which may represent part of the Upper Birkhill Shale group.

Cow Linn, Fruid Water.—About a mile and a half from the source of the Fruid Water, north of Hartfell, below the foot of Black Cleuch, the stream flows through a rocky gorge in greywackes and grits. Near the bend of the stream, in an excellent exposure of the Lower Birkhill Shales, these strata are arranged in an isoclinal fold, the lowest beds being in the centre, and with the higher zones on either side. From the accompanying lists of fossils, which are abundant and well preserved, obtained from this locality, it is evident that all the main zones of the Lower Birkhill division are represented. The *Monograptus gregarius* zone has yielded the following forms:

Monograptus gregarius (Lapw.)
,, *leptotheca* (Lapw.)
,, *cyphus* (Lapw.)
,, *triangulatus* (Hark.)
,, *lobiferus* (M'Coy.)
Monograptus tenuis (Portl.)
Diplograptus tamariscus (Nich.)
Petalograptus folium (His.)
Rastrites peregrinus (Barr.)

From the two lower zones the following fossils were exhumed:

Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus Swanstoni (Lapw.)
Monograptus tenuis (Portl.)
Climacograptus normalis (Lapw.)
Dawsonia campanulata (Nich.)

This band is of special importance, as it still yields the characteristic fossils of the *Monograptus gregarius* zone. To the north-west of this outcrop this particular horizon is no longer met with. On all the anticlines between the Cow Linn and the river Tweed above the Crook, only the two lower zones of the Lower Birkhill beds are represented.

To the south-west of the Cow Linn section, the prolongation of this band is met with in the White Cleuch, a branch of the Carterhope Burn, where grey and dark shales occur.

Powskein Burn.—In a small tributary of this burn—joining the Tweed about a mile to the north of the Permian

outlier at Erickstane — a mass of grey and dark shales is exposed, from which no fossils have been obtained. They resemble those beds associated with the Lower Birkhill Shales at the head of Blackhope Burn on Hartfell.

Howecleuch, Eyan Water.—At Nether Howecleuch, near the junction of Harthope Burn with the river Eyan, an exposure of black sandy shale in an isoclinal fold may be seen in the midst of the Queensberry grits. The band is only a few feet broad, but it has yielded some Lower Birkhill fossils.

Fruid Water.—On the east side of the valley, about a mile below Fruid Farmhouse, in a small gully above the road, black sandy shales are met with in the grits, which are continued north-eastwards into the Menzion Water. Similar strata occur in the Hawkshaw Burn, a tributary of the Fruid Water, about a mile north of Carterhope.

Foot of Fruid Water, near junction with the Tweed.—Near the foot of Fruid Water interesting sections are found of the representatives of the Moffat series. For several miles this stream flows along an alluvial flat which conceals the rocks from view, but eventually it careers through a rocky gorge carved out of the pebbly bands of the Queensberry grits. Just above the gorge it traverses for about 100 yards a succession of dark blue, almost black, and grey shales, representing the two lower zones of the Lower Birkhill division. To the north of the grits the dark and grey shales once more appear. The strata have a constant dip down stream or towards the north at angles varying from 45° to 50°. It is highly probable that the dark shales are repeated by means of isoclinal folds. The most northerly outcrop is shifted by a fault trending north, which cuts obliquely across the stream.

It is a remarkable fact that in these exposures the two lower zones of the Lower Birkhill Shales have entirely changed their lithological characters. Instead of the persistent bands of black flaggy shales that run through the whole of the Moffat region, abundantly charged with fossils, the shales are now dark blue, hardly black, and seldom contain fossils. Indeed, after a most rigorous search by Mr. Macconochie, only the few following forms were obtained:

Diplograptus acuminatus (Nich.)	*Climacograptus normalis* (Lapw.)
,, *vesiculosus* (Nich.)	

The more northerly band can be traced north-east to the Menzion Burn and to the Talla Water above Dykehead.

Tweed Valley.—On referring to the map (Sheet 16) it will be seen that a band which represents part of the Moffat series can be traced along the valley of the Tweed from the foot of the Talla Water, south-west to the bend above Glenbreck. Where this band is exposed in the Tweed at Rigs it has yielded the following forms:

Diplograptus acuminatus (Nich.)	*Climacograptus normalis* (Lapw.)
,, *vesiculosus* (Nich.)	*Dimorphograptus* (?)

Here the fossiliferous zone is only a few inches thick, and fossils are extremely rare.

At other points along this line of outcrop between Glenbreck and the Talla Water the following additional fossils have been obtained: *Climacograptus innotatus* (Nich.), *Dimorphograptus elongatus*, and *Diplograptus*. One of these fossiliferous localities occurs at the bridge across the Tweed near the foot of the Talla Water.

On three successive anticlines in the Oliver Burn, north of the Tweed, three representatives of part of the Moffat series make their appearance. The folds are isoclinal, the strata having a uniform dip to the north-west at angles varying from 45° to 70°.

About two miles to the south-west of the Tweed at Glenbreck, several anticlines of these fossiliferous Moffat Shales occur in close association with the outcrops of the Pinstane Conglomerate. Here they yield fossils very sparingly, but in numbers sufficient to prove their horizon.

A glance at the map will show that along the northern margin of the Llandovery and Tarannon area, between the valley of the Tweed and Kingledores Burn, and westwards towards the Midlock Water at Howe Cleuch, several local isoclinal folds expose similar dark blue shales which are probably the representatives of the very basal bands of the Birkhill division. In these bands, *Diplograptus vesiculosus* has not been detected, but fragments of certain graptolites which are the associates of that species and *D. acuminatus* at the foot of the Fruid Water and in the Tweed bands have been found. Amongst them there is a small and very attenuated form of *Climacograptus* which seems to be characteristic of the bands near the margin of the Tarannon area. Indeed, it is mainly by the aid of these bands that the boundary line has been drawn at the base of the Tarannon and Llandovery rocks in the north-west part of Sheet 16. But it must be clearly borne in mind that fossils are extremely rare and poorly preserved. In the exposures along the boundary line neither *Diplograptus vesiculosus* nor *D. acuminatus* has been detected. It must be frankly admitted that there is no well-marked fossiliferous band which can be traced continuously at the base of the Llandovery and Tarannon series in the northern area. These facts have an important bearing on the lateral variation of the Moffat series as we pass towards the Abington and Lead Hills districts.

Summarising the evidence given in this chapter regarding the modification of the Moffat zones between Dobb's Linn and the margin of the Tarannon area, it is observable that there is a gradual change in the lithological characters of the members of the Birkhill division and a gradual disappearance of the fossiliferous zones as we pass towards the north-west. Along the line of the Hartfell band the fossiliferous zones of the Upper Birkhill division have either wholly or partially disappeared. The last appearance of the *Monograptus gregarius* zone, which is the highest band of the Lower Birkhill Shales, occurs on the anticline at Cow Linn near the head of the Fruid Water.

At the foot of the Fruid Water and in the bed of the Tweed between the foot of the Talla Water and Glenbreck, though specimens of *Diplograptus vesiculosus* and *D. acuminatus* have been obtained, the lithological characters of the zones marked by these species have been considerably changed. Fossils are extremely rare in the bands of dark blue shale.

North of the Tweed as far as the line selected to mark the base of the Llandovery Rocks, *Diplograptus vesiculosus* and *D. acuminatus*, characteristic of the two lower zones of the Lower Birkhill Shales, seem to have disappeared, and there are only traces of graptolites which are the associates of these species in the bands of the Tweed. It is clear, therefore, that within a distance of nine miles from the typical Dobb's Linn section along the northern margin of the Llandovery area, the characteristic zonal fossils of the Birkhill division have disappeared.

CHAPTER VIII.

THE CENTRAL BELT—*continued.*

BLACK SHALE BANDS IN THE AREA BETWEEN THE ANNAN AND THE NITH.

THE Glenkiln Section.—The section in the Glenkiln Burn about three-quarters of a mile above Kirkmichael Manse, Dumfriesshire, has been fully described by Professor Lapworth in his paper on "The Moffat Series." From this section the lowest division of the series derives its name, because it yields the characteristic fossils of the group in greatest abundance.

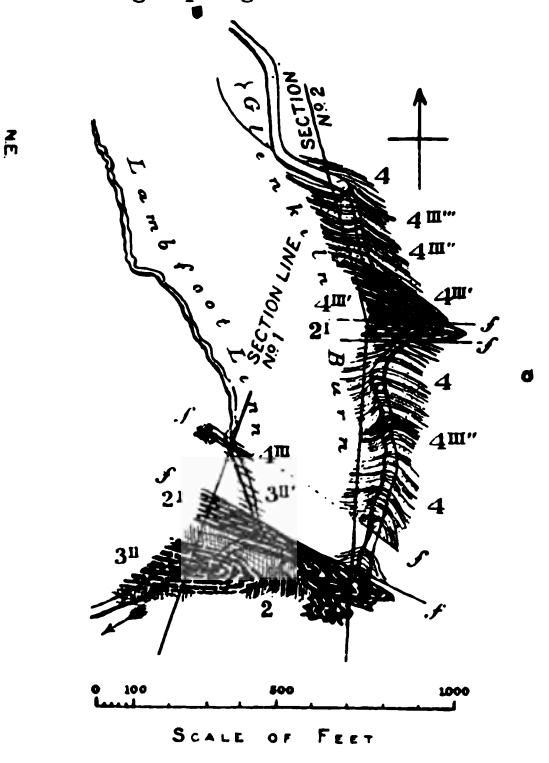


FIG. 25.—Plan of Strata in Glenkiln Burn, Kirkmichael, Dumfriesshire.

2. Glenkiln mudstones and cherts. 2^{I}. Glenkiln black shale. 3^{II}. Lower Hartfell Shales. $3^{II'}$. Barren Mudstones. 4^{III}. Lower Birkhill Shales. $4^{III'}$. Upper Birkhill Shales. $4^{III''}$. *Maximus*-zone. $4^{III'''}$. *Exiguus*-zone. 4. Tarannon series. f. Faults. ~ Recent alluvium.

From the accompanying plan (Fig. 25) and horizontal sections it will be seen that the original sequence of the strata has been much disturbed by faulting. A still further disadvantage appears in the fact that as the observer ascends the stream from the Manse he first finds an exposure of the Lower Hartfell black shales, which, owing to a blank in the section, are not in visible continuity with other strata to the south. The Hartfell black shales at the latter point form an inverted syncline dipping to the north-west. At the edge of the south limb of this fold and on the left bank of the burn there is an exposure of grey and black shales which contain the following characteristic forms of the *Climacograptus Wilsoni* zone in excellent preservation (3^{II}, Fig. 26):

Climacograptus Wilsoni (Lapw.)
,, *Schärenbergi* (Lapw.)
,, *peltifer* (Lapw.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)
Corynoides calycularis (Nich.)

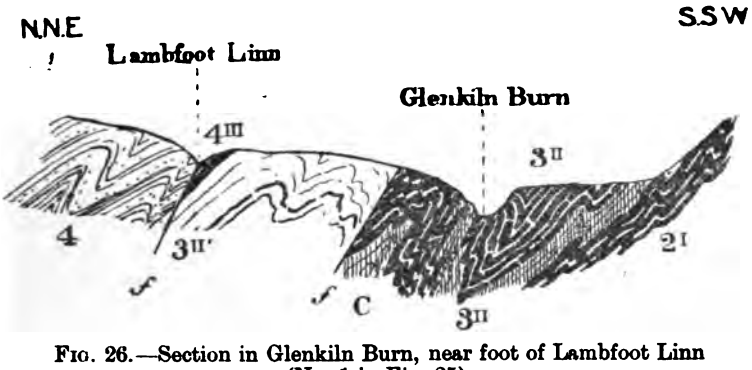


FIG. 26.—Section in Glenkiln Burn, near foot of Lambfoot Linn (No. 1 in Fig. 25).

C. Radiolarian chert. *(For further explanation, see Fig. 25.)*

Overlying the foregoing strata and occupying the centre of the trough some flaggy shales have supplied the following assemblage of fossils:

Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
,, *tubuliferus* (Lapw.)
Corynoides calycularis (Nich.)
Diplograptus foliaceus (Murch.)
Diplograptus perexcavatus (Lapw.)
Lasiograptus margaritatus (Lapw.)
Dicellograptus moffatensis (Carr.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)

These fossiliferous shales are immediately followed by those forming the *Climacograptus Wilsoni* zone, on the north limb of the syncline, which there dip to the north at an angle of 80°. At this point the section is of importance, as it shows a gradual passage downwards into bands of chert with radiolaria, and mudstones. Indeed the evidence of the intercalation of radiolarian mudstones and cherts at the base of the *Climacograptus Wilsoni* zone, furnished by this stream, confirms the conclusion already arrived at from a consideration of the typical sections

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Glenkiln division are here admirably exposed, and yield the following characteristic assemblage of fossils:

Didymograptus superstes (Lapw.)
,, *serratulus* (Hall.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Thamnograptus typus (Hall.)
Dicranograptus formosus (Hopk.)
,, *Nicholsoni* (Hopk.)
,, *ramosus* (Hall.)
Dicellograptus patulosus (Lapw.)
,, *intortus* (Lapw.)
,, *moffatensis* (Carr.)
,, *sextans* (Hall.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *cælatus*, var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *Whitfieldi* (Hall.)
Lasiograptus bimucronatus (Nich.)
Acrotreta Nicholsoni (Dav.)

These Glenkiln Shales are succeeded on the north side, in the tributary streamlet, by grey mudstones, which, from their lithological characters, are probably the Barren Mudstones of the Upper Hartfell group. If this correlation be correct, then the mudstones must be faulted against the Glenkiln Shales to the south. These mudstones are inclined to the north for a distance of eighty yards, and by means of another dislocation they are brought into contact with greywackes and shales containing black shale seams of Llandovery age.

Resuming the section in the Glenkiln Burn, the observer finds another exposure of Glenkiln Shales about 100 yards up stream from the foot of the tributary rivulet, at a point where the Glenkiln Burn takes a bend to the north. Here, on the south bank, the Glenkiln Shales appear, and yield graptolites in an imperfect state of preservation. Northwards they are followed by grey Barren Mudstones, the latter being succeeded by greywackes and shales exposed continuously for a distance of 200 yards up the stream, where the Glenkiln Shales reappear. Two thin seams of silky shales are found in the midst of these greywackes and shales, yielding *Rastrites maximus, M. exiguus*, &c. (Fig. 27).

This higher exposure of Glenkiln black shales, charged with its characteristic fossils, is truncated by faults to the north and south. In the latter direction it is brought into conjunction with the Tarannon greywackes and shales, while on the north side it is thrown against the members of the Lower Birkhill group, which are there highly contorted. Owing to the faulting and contortion the black shales and mudstones of the Birkhill division are very shattery, but notwithstanding this feature the following forms have here been obtained from various sub-zones of the highest group of the Moffat series (Fig. 27).

Diplograptus acuminatus (Nich.)
,, *tamariscus* (Nich.)
Climacograptus normalis (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *lobiferus* (M'Coy.)
,, *leptotheca* (Lapw.)
,, *Hisingeri* (Carr.)
Monograptus cyphus (Lapw.)
,, *spiralis* (Geinitz.)
,, *spinigerus* (Nich.)
Rastrites peregrinus (Barr.)
Petalograptus folium (His.)
Peltocaris aptychoides (Salter.)
Discinocaris browniana (Woodw.)
Discinoid shell.

These Birkhill Shales are followed in normal order by greywackes and shales, in the midst of which occurs a thin band of shales yielding *Rastrites maximus*. Still further up stream, at a prominent bend, two thin seams of dark silky shales afford fine examples of *Rastrites maximus*, *Monograptus exiguus*, *M. priodon*, *Retiolites perlatus*. It is probable that the higher of these fossiliferous seams in the coarser sediments yielding *M. exiguus*, *M. priodon*, &c., may be of Tarannon age ($4^{III'''}$, Fig. 25).

Glancing for a moment at the horizontal sections (Figs. 26, 27), which illustrate the structure of the highly faulted exposures in the Glenkiln Burn, one may see how their present complicated relations may be satisfactorily accounted for on the supposition that they originally formed two anticlines and synclines, subsequently truncated by faults. About five miles to the north-east of the section just described, there are several exposures of the black shale series in the Duffkinnel Water near Raehills, and in the Linholm Burn above Glenhall.

Duffkinnel Water.—Ascending the stream from Duffkinnel foot, we find brown crusted flags, greywackes, and shales inclined to the north-west at an angle of about 30°. About 300 yards from the mouth of the stream black shales appear on the west bank, much crumpled and shattered and thrown into sharp folds, from which no determinable fossils were obtained. These strata are succeeded by an exposure of the Barren Mudstones, followed by black shales dipping towards the north. Still higher up on the east bank of the stream black shales appear, much smashed and broken, but yielding a few fossils of the Lower Hartfell group. Crossing two thin felsite dykes, we find the Barren Mudstones, followed by greywackes and shales pierced by a dyke of felsite.

These strata are succeeded by a fine development of the Lower Birkhill group, in which the flaggy black shales of the *Diplograptus vesiculosus* zone are conspicuously seen in a cliff on the west bank. From this exposure the following fossils were obtained:

Diplograptus vesiculosus (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus elongatus (Lapw.)
Monograptus attenuatus (Hopk.)
,, *gregarius* (Lapw.)
Monograptus tenuis (Portl.)
Climacograptus rectangularis (M'Coy.)
,, sp.

Above these flaggy black shales come thin fissile black shales and clays yielding a group of fossils characteristic of the higher members of the Lower Birkhill group:

Monograptus lobiferus (M'Coy.)
,, *leptotheca* (Lapw.)
,, *triangulatus* (Hark.)
,, *attenuatus* (Hopk.)
,, *tenuis* (Portl.)
,, *gregarius* (Lapw.)
,, *cyphus* (Lapw.)
Monograptus spiralis (Geinitz.)
Diplograptus tamariscus (Nich.)
,, *confertus* (Nich.)
Climacograptus normalis (Lapw.)
,, sp.
Rastrites peregrinus (Barr.)
,, *hybridus* (Lapw.)

A few yards to the north of this exposure of the Birkhill Shales, purple and red shales and flags are seen in the stream,

which continue north to the footbridge. Though this lower section of the black shale series in the Duffkinnel Water cannot be said to be satisfactory, yet the evidence points on the whole to the conclusion that the members were arranged originally in an isoclinal arch, dipping to N.N.W. The northern limb of the arch is tolerably complete, the various zones from the top of the Lower Birkhill group to the Hartfell black shales being visible. It is clear, however, that a part of the southern limb is absent.

About half a mile to the north of the foregoing section there is another exposure of the Moffat series in the Duffkinnel Water, a few yards above a small cottage named Glenhall. As the section is not continuous, the physical relations of the black shales cannot be determined, but from the following list of fossils gathered from this isolated outcrop, it is clear that they belong to the Birkhill group:

Monograptus argutus (Lapw.)
,, *attenuatus* (Hopk.)
,, *communis* (Lapw.)
,, *gregarius* (Lapw.)
,, *cyphus* (Lapw.)
,, *leptotheca* (Lapw.)
,, *lobiferus* (M'Coy.)
,, *Sandersoni* (Lapw.)
,, *spinigerus* (Nich.)
,, *tenuis* (Portl.)
,, *triangulatus* (Hark.)
,, *spiralis* (Geinitz.)
Diplograptus tamariscus (Nich.)
,, *confertus* (Nich.)
Cephalograptus cometa (Geinitz.)
Petalograptus folium (His.)
,, *palmæus* (Barr.)
Rastrites peregrinus (Barr.)
,, *hybridus* (Lapw.)
Climacograptus normalis (Lapw.)
,, or *Diplograptus* with double rootlets.
Dawsonia campanulata (Nich.)
Retiolites, sp.
Peltocaris aptychoides (Salter.)
Discinocaris browniana (Woodw.)
,, *gigas* (Woodw.)

Linholm Burn.—About 200 yards above Glenhall the Duffkinnel Water is joined by the Linholm Burn on the north bank, in which there is a good exposure of the higher members of the Moffat series, belonging almost exclusively to the Birkhill group. The section begins at the footbridge near the mouth of the burn, and continues for about 200 yards up the stream.

At the footbridge on the east bank of the stream black shales and clays dip northwards at 85°, which, from the accompanying list of fossils, evidently belong to the higher zones of the Lower Birkhill group:

Rastrites peregrinus (Barr.)
Monograptus attenuatus (Hopk.)
,, *tenuis* (Portl.)
,, *triangulatus* (Hark.)
Monograptus cyphus (Lapw.)
Diplograptus tamariscus (Nich.)
Petalograptus folium (His.)
Climacograptus normalis (Lapw.)

Further up the stream on the left bank we encounter black and grey mudstones yielding *Cephalograptus cometa*, followed by black and grey shales, from which specimens of *Monograptus spinigerus* were obtained in fine preservation.

From this point northwards to where the section of the black shale series ceases, we find exposures from which forms belonging partly to the lower division and partly to the upper division of

the Birkhill group have been obtained. Close to the northern limit of the section the *Cephalograptus cometa* zone reappears. Hence it is probable that the Moffat series in this section may have originally formed two or more minor anticlines. This supposition is confirmed by the evidence from the Duffkinnel and Broadshaw Waters along the same line of strike to the south-west. In the latter sections three well-marked anticlines occur in the overlying greywackes and shales. There can be little doubt that these are merely the prolongations of the axial folds which in the Linholm Burn are represented in the Birkhill group. This feature is worthy of note, because it helps us to realise the extent of the plication of the Tarannon formation, where the isoclinal folding cannot be demonstrated by the occurrence of the black shale series.

District of Wee Queensberry Hill.—In the extreme north-west corner of Sheet 10, several sections of the Moffat series are exposed in the head waters of the Ae, one of which is of special interest from the clear relations of the strata and from the excellent preservation of the fossils. These exposures occur in the Pishnack and Bran Burns, draining the slopes of the Wee Queensberry Hill and flowing into the Water of Ae.

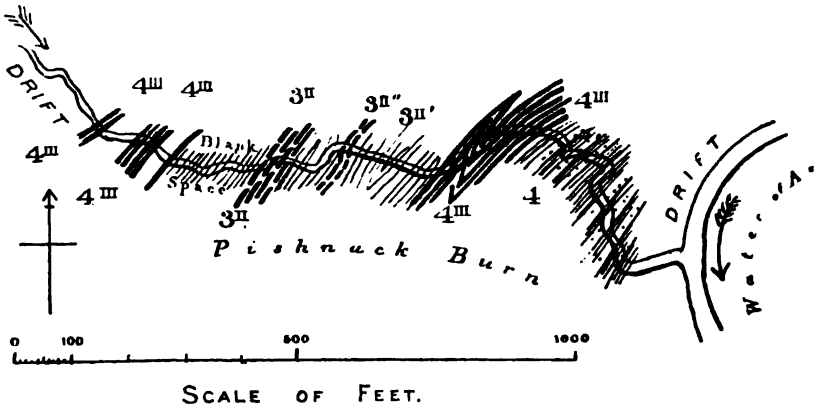


FIG. 28.—Plan of Strata in Pishnack Burn, Water of Ae, Dumfriesshire.

3II. Lower Hartfell Shales. 3II'. Barren Mudstones. 3II''. *Anceps*-zone.
4III. Lower Birkhill Shales. 4. Tarannon greywackes and shales.

The best section is exposed in the lower part of the Pishnack Burn, beginning not far above the point where it joins the Water of Ae. Ascending the stream from the foot, we find greywackes and shales of the Tarannon formation having a dip to the north-west, succeeded by a considerable development of grey and greenish shales, with occasional bands of yellow decomposing greywacke. From the accompanying plan (Fig. 28) and horizontal section (Fig. 29), the position of the various sub-divisions of the black shale series will be seen at a glance. Beyond the green crumbly shales no rock is exposed for a few

yards, but soon a fine display of black shales is encountered, followed by alternations of black shales and clays. In one of the black shale bands, yielding fossils in profusion and in good preservation, the following species were found :

Monograptus argutus (Lapw.)	*Diplograptus tamariscus* (Nich.)
,, *attenuatus* (Hopk.)	,, sp.
,, *communis* (Lapw.)	*Climacograptus normalis* (Lapw.)
,, *leptotheca* (Lapw.)	*Petalograptus ovato-elongatus* (Kurck.)
,, *lobiferus* (M'Coy.)	*Diplograptus confertus* (Nich.)
,, *Hisingeri* (Carr.)	*Dawsonia campanulata* (Nich.)
,, *spiniferus* (Nich.)	*Lingula* sp.
,, *Sandersoni* (Lapw.)	*Obolella* sp.
,, *spiralis* (Geinitz.)	Discinoid shell.
,, *tenuis* (Portl.)	Sponge-like markings.
,, *triangulatus* (Hark.)	

From the foregoing list it is apparent that these black shales and clays belong to the middle zones of the Birkhill division.

Next in order comes an excellent exposure of flaggy black shales yielding characteristic specimens of *Diplograptus vesiculosus*, together with *Monograptus gregarius*, *M. lobiferus*, *M. attenuatus*, *Dimorphograptus elongatus*.

On the opposite bank of the stream there is an anticlinal fold in black shales in which *Diplograptus acuminatus* was detected.

A few yards higher up the observer is confronted with a prominent exposure of the Barren Mudstones, forming a cliff on the left bank of the stream. A small fault evidently intervenes between the black shales at the base of the Birkhill group and the Barren Mudstones, because both occur in the same line of strike, but it has little effect on the relative position of the beds. In a band of bleached shales was found *Dicellograptus anceps*, proving the horizon of the Barren Mudstones ($3^{II''}$).

A short distance up the stream bleached black shales are encountered yielding the following fossils characteristic of the Hartfell black shales: *Climacograptus caudatus*, *C. tubuliferus*, *Diplograptus perexcavatus* (3^{II}, Figs. 28, 29).

Unfortunately, a portion of the section of the Moffat series is concealed at this point owing to a thick covering of superficial deposits, but not far to the north black shales again appear, containing *Diplograptus vesiculosus* and *D. acuminatus* in a fine

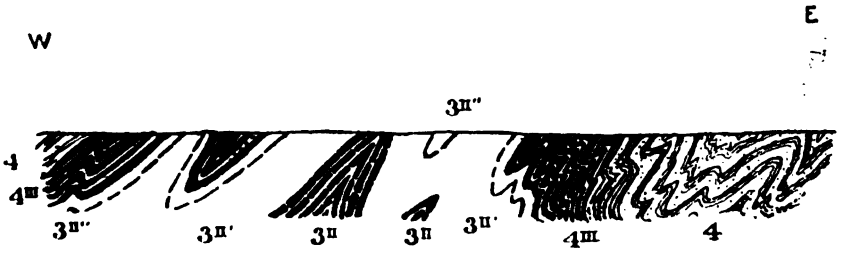


FIG. 29.—Section near foot of Pishnack Burn.

(For explanation, see Fig. 28.)

state of preservation. With the *Diplograptus vesiculosus* zone is associated a band of black grit. Beyond this point the solid rocks are buried underneath the drift for a little distance.

From the evidence supplied by this section, it is clear that the members of the black shale series are here arranged in an anticlinal fold, the lowest beds in the core of the arch being the Hartfell black shales. The strata, with the exception of the sharp anticline in the *Diplograptus acuminatus* zone south of the Barren Mudstones, are all inclined to the N.W. Hence it follows that the arch is an isocline and the southern limb is inverted. The section further shows how dark grits are associated with one of the prominent lower zones of the Birkhill group—a feature which is prevalent in some of the folds in the ground to the north-east in Sheet 16.

About 700 yards from the mouth of the Pishnack Burn, at a point where it takes a sudden bend to the south-west, it is joined by a small streamlet on the east bank. In this streamlet, just above an angle in its course, about 60 yards from the Pishnack Burn, there is an interesting exposure of the black shale series on the west bank, where the strata form a sharp anticline. In the centre of the arch the black shales, which are associated with clays and mudstones, contain fossils characteristic of the Upper Birkhill group, and to these succeed black shales and clays belonging to the *Monograptus spinigerus* zone. The *Rastrites maximus* zone is probably represented by the greywackes and shales immediately overlying the black shale series.

At the head of the Pishnack Burn, on the southern slope of the Wee Queensberry Hill, at a height of about 1300 feet above the sea, black shales reappear belonging to the Birkhill group. In a scar on the eastern slope, about 30 yards above the stream, there is an arch in grey mudstones with black shale seams yielding *Monograptus lobiferus*. Not far above this point there are several exposures of folded black shales and clays, in which were detected the following fossils: *Cephalograptus cometa, Peltocaris aptychoides, Monograptus cyphus, M. triangulatus, M. leptotheca, M. Sedgwicki, Rastrites peregrinus, Climacograptus normalis*, &c.

These black shales and clays can be followed along a hollow named the Cat Slack, towards the south-west, in the direction of the Bran Burn, bounded by crags of grit on either side.

Descending the Bran Burn, it is joined by a small stream on the east bank not far below the point where it enters Sheet 10. At the mouth of this streamlet another anticline in the Tarannon greywackes and shales reveals various zones of the Birkhill group, as is evident from the fossils obtained from the black shales: *Monograptus spinigerus, M. tenuis, M. triangulatus, Diplograptus tamariscus, Climacograptus normalis.*

The foregoing sections of the Moffat series in the district of the Wee Queensberry Hill are chiefly confined to members of the Birkhill group. Only in the lower section of the Pishnack Burn do we reach the horizon of the Hartfell black shales, and in no instance have the representatives of the Glenkiln group

been observed. Where the sections are continuous, even though the axial folds be isoclinal, it can be demonstrated that the lowest zones occupy the centre of the anticlines, succeeded by the higher zones on either side.

Crook Burn, Tributary of the Daer Water.—As the observer passes northwards to the tributaries of the Clyde, he finds evidence bearing on the modification of the representatives of the Birkhill Shales. For example, in the Crook Burn, which rises on the north slope of Queensberry Hill and joins the Daer Water at Kirkhope shepherd's house, there are two exposures of bands belonging to the Moffat series. The more southerly occurs in a rivulet on the east side of the Crook valley, one mile south of the shepherd's house of Whiteholm. Ascending this streamlet, we find contorted black shales which have supplied the following assemblage of fossils, characteristic mainly of the basal zone of the Birkhill group:

Diplograptus acuminatus (Nich.)
,, *tamariscus* (Nich.)
Dimorphograptus elongatus (Lapw.)
Climacograptus, sp.
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
Dawsonia campanulata (Nich.)

These black shales are underlain by Barren Mudstones dipping to the north-west, but their relations to the surrounding strata are not visible.

A marked change supervenes in the strata as they are followed down the valley for a distance of three-quarters of a mile. In the banks of the stream black micaceous sandy shales are interleaved in grey shales, which alternate with bands of grit about six inches thick, the whole series dipping to the north-west. The following forms were collected from the thin dark films in the coarser sediments: *Monograptus Sandersoni*, *M. lobiferus*, *Diplograptus tamariscus*, and *Climacograptus*.

Still further north, beyond highly folded grits, greywackes and shales, dark films, in which graptolites occur sparingly, appear in a zone of slates traceable from the Caledonian Railway one mile south of Elvanfoot, along the southern base of the Lowther Hills to the Dalveen Pass. They are associated with greywackes and occasional grits. In a slate quarry, by the side of the road leading to Dalveen Pass, opposite the junction of the Daer and Portrail Waters, specimens of *Climacograptus* and *Diplograptus* were obtained. These beds are regarded as marking the northern base line of the Llandovery and Tarannon Rocks in this part of the tableland.

BLACK SHALE BANDS IN THE AREA BETWEEN NITHSDALE AND THE RIVER CREE.

In the belt of hilly ground between Nithsdale and the valley of the Ken, the axial folds revealing representatives of the Moffat series within the Tarannon area lie mainly along a belt of ground extending from the valley of Glenessland, in the

parish of Dunscore, by the Urr Water near Corsock to the Barend Burn near Loch Ken.

In the basin of Glenessland the black shale series appears on three folds at no great distance from each other.

Bogrie and Castramon.—The most northerly of these folds runs along a line stretching from the Bogrie Burn north of the Bogrie Tower to the Castramon Burn. Beginning with the section in Bogrie Burn (Fig. 30), we find a sequence from the Hartfell black shales through the Barren Mudstones to the Birkhill Shales, the strata of which are vertical, or nearly so,

FIG. 30.—Section in Bogrie Burn, Glenessland, Dumfriesshire. (Length, 600 yards.)

3II. Lower Hartfell Shales. 3II'. Barren Mudstones. 4III. Birkhill group. 4. Greywacke and shale (Llandovery-Tarannon).

being arranged in an anticlinal fold with the Hartfell Shales in the centre. The latter are well exposed in the core of the arch, followed by the Barren Mudstones on either side. The Hartfell black shales near their southern limit, close to the Barren Mudstones on the south limb of the fold, contain the following forms:

Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
Dicellograptus, sp.
Lasiograptus margaritatus (Lapw.)
Corynoides calycularis (Nich.)

About five feet from the foregoing locality, on the east bank, further up stream, abundant specimens of *Diplograptus foliaceus* were found crowding the surface of the black shale seam.

On the opposite or west bank, four yards up stream, the following forms were collected from the black shales:

Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Dicranograptus ramosus (Hall.)
Dicellograptus, sp.
Leptograptus, sp.

On the north limb of the fold the Hartfell black shales are succeeded by the Barren Mudstones, which occupy the course of the stream for a distance of 16 yards, displaying the typical characters of this sub-division in the Moffat region. These are overlain by black shales, which at the junction furnish *Climacograptus*, *Diplograptus tamariscus*, *Dimorphograptus elongatus*, *Monograptus*, and are followed by black shales of the *D. vesiculosus* zone

and bands yielding *M. gregarius*. These Lower Birkhill shales are here overlain by grey shales and greywackes.

Returning now to the south limb of the fold, the observer may note that thin layers of chert with radiolaria are associated with the Barren Mudstones in contact with the Hartfell black shales. This association probably indicates a recurrence of clear-water conditions similar to those which prevailed in Upper Arenig time. Again, near the base of the Barren Mudstones, a thin seam of black shales, two inches thick, occurs, yielding *Dicranograptus*, *Dicellograptus*, and *Climacograptus*. From this outcrop southwards to the Birkhill Shales, a distance of 36 yards, the space is occupied by Barren Mudstones which are evidently repeated by folding. Near the top of this sub-division a thin seam of dark or black shale occurs, and close to the junction with the overlying Birkhill group an intrusive dyke makes its appearance. From the Birkhill Shales on the south limb of the arch the following forms were collected:

Diplograptus confertus (Nich.)
,, *vesiculosus* (Nich.)
,, *tamariscus* (Nich.)
Climacograptus normalis (Lapw.)
,, *innotatus* (Nich.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *leptotheca* (Lapw.)
,, *gregarius* (Lapw.)

These strata are succeeded by greywackes and shales, which, at the sharp bend in the stream to the south-west, contain a fold of black shales yielding *Diplograptus tamariscus* and *Climacograptus normalis*.

About 100 yards south-west from the junction of the Castramon Burn with the Shillingland Burn, and on the south-east side of the stream, a heathery knoll of black shales about 15 yards long shows the junction of the Hartfell black shales with the Barren Mudstones. The latter occur on the south-east side of the knoll, and by stripping off the heathery covering the junction line can be laid bare at the north-east corner. From the band of black shales in contact with the Barren Mudstones, *Pleurograptus linearis* was collected. The following forms were obtained from this exposure:

Pleurograptus linearis (Carr.)
Diplograptus quadrimucronatus (Hall.)
,, *foliaceus* (Murch.)
Leptograptus capillaris (Carr.)
,, *flaccidus* (Hall.)
Climacograptus, sp.
Dicranograptus, sp.
Dicellograptus Forchhammeri (Geinitz.)
,, sp.

The Hartfell black shales seem to form the core of the arch, for as we proceed south-westwards the Barren Mudstones appear on the north limb near the Castramon Burn with a north-west dip.

Mark Cleuch.—About a third of a mile to the south of the axial fold just referred to, the Moffat Shales reappear in the Mark Cleuch, one of the tributaries of the Glenessland Burn, which rises on the north slope of the Craigdasher Hill. At the south limit of the alluvium, and about 200 yards from the foot of the

burn, sandy shales and greywackes occur on the east bank, to which succeed blue-grey shales dipping up stream at about 70°. In the bands about two feet from the greywackes the following forms were collected in splendid preservation:

Monograptus gregarius (Lapw.)
,, *triangulatus* (Hark.)
,, *Sedgwicki* (Portl.)
,, *Hisingeri* (Carr.)
,, *lobiferus* (M'Coy.)
,, *attenuatus* (Hopk.)
,, *tenuis* (Portl.)
,, *Sandersoni* (Lapw.)
Diplograptus tamariscus (Nich.)
,, *confertus* (Nich.)
Petalograptus palmæus (Barr.)
Rastrites peregrinus (Barr.)
Climacograptus normalis (Lapw.)
Discinocaris browniana (Woodw.)
Dawsonia campanulata (Nich.)

The foregoing assemblage would seem to indicate that the highest visible zone at this locality is that of *Monograptus gregarius*. The beds at this exposure consist of alternations of grey clays and black shales, resembling the normal types of this zone in the Moffat region.

Following the stream upwards, we find on the left bank, beyond the stone fence, blue shales and greywackes with black shales, the latter yielding fragments of graptolites. A few yards further up on the east bank, alternations of black shales and grey clays are exposed with blue shales. These contain the fossils of the *M. gregarius* zone, and are succeeded by the shales of the *D. vesiculosus* zone, visible on the right bank up stream, from which the following species have been obtained:

Diplograptus vesiculosus (Nich.)
,, *confertus* (Nich.)
Climacograptus normalis (Lapw.)
Monograptus gregarius (Lapw.)
Monograptus attenuatus (Hopk.)
,, *tenuis* (Portl.)
,, *leptotheca* (Lapw.)

South-westwards, on the right bank, an arch of the Barren Mudstones appears, overlain by the Birkhill black shales. The beds of the *D. vesiculosus* zone, visible on the top of the cliff, have here been slightly hardened by various intrusive dykes.

The most southerly exposure in the bed of the stream yields an assemblage of graptolites characteristic of the *Monograptus gregarius* zone:

Monograptus gregarius (Lapw.)
,, *lobiferus* (M'Coy.)
,, *leptotheca* (Lapw.)
,, *attenuatus* (Hopk.)
Monograptus tenuis (Portl.)
Climacograptus normalis (Lapw.)
Diplograptus tamariscus (Nich.)
Dawsonia campanulata (Nich.)

From the foregoing description it is apparent that the members of the Moffat series are here arranged in an axial fold, the centre being occupied by the Barren Mudstones, succeeded by the Lower Birkhill Shales on both sides of the fold.

Nether Whiteside.—About half a mile to the south-east of the line of strike of the foregoing band, the Moffat Shales reappear along another anticlinal arch, the exposures being restricted to two localities—one to the east of Nether Whiteside Farmhouse, and the other on the same strike on Whiteside Moor.

About 450 yards to the east of Nether Whiteside Farmhouse an isolated exposure lies at the northern base of the slope of Nethertown Moor. Here the radiolarian cherts appear associated with black shales yielding *Didymograptus superstes*, *Climacograptus bicornis*, *Diplograptus foliaceus*, &c. By means of fragments in the soil the black shales can be traced across the Nether Whiteside Moor to a point about a quarter of a mile S.S.E. of Upper Whiteside, where alternations of black shales and grey clays appear, yielding the following forms:

Monograptus gregarius (Lapw.)	*Diplograptus tamariscus* (Nich.)
,, *tenuis* (Portl.)	,, *confertus* (Nich.)
,, *leptotheca* (Lapw.)	*Rastrites peregrinus* (Barr.)
,, *triangulatus* (Hark.)	*Dawsonia campanulata* (Nich.)

Water of Urr.—As the observer passes towards the south-west from Glenessland, he encounters in the Water of Urr, from Nether Glaisters to near Crogo Tower, a series of folds that reveal the members of the Moffat series. Beginning with the section of the southmost axial fold, displayed on the west bank of the stream, about 300 yards north-west of Crogo Tower, he finds the representatives of the Moffat series arranged in the form of an arch with the Barren Mudstones in the centre. On the south limb of the fold, where a footbridge crosses the stream, the Lower Birkhill Shales succeed and afford the following forms:

Diplograptus acuminatus (Nich.)	*Dimorphograptus elongatus* (Lapw.)
,, *vesiculosus* (Nich.)	,, *Swanstoni* (Lapw.)
,, *tamariscus* (Nich.)	*Monograptus attenuatus* (Hopk.)
,, *confertus* (Nich.)	,, *Sandersoni* (Lapw.)

On the north limb of the fold, at the northern limit of the shales, the following fossils were collected:

Monograptus gregarius (Lapw.)	*Dimorphograptus elongatus* (Lapw.)
,, *Sandersoni* (Lapw.)	*Climacograptus normalis* (Lapw.)
Dimorphograptus Swanstoni (Lapw.)	*Diplograptus confertus* (Nich.)

About 300 yards further north, near a cottage by the side of the Urr, an isolated exposure of the black shales yielded specimens of *Dimorphograptus Swanstoni*, *Climacograptus normalis*, &c.

When the stream is ascended to a point near the old mill of Crogo—about 100 yards south of the mill, now in ruins—a fine exposure of the Moffat series, with the Barren Mudstones in the centre, is met with, followed on the north side by the Lower Birkhill Shales. Here the *D. vesiculosus* zone is well seen, fine specimens of that zonal form being obtainable, together with *Dimorphograptus Swanstoni*, *D. elongatus*, *Monograptus tenuis*, *Climacograptus normalis*.

Along the strike of this outcrop, in knolls among the fields to the north of the farmhouse of Upper Bar, numerous exposures may be noticed of the Barren Mudstones and Birkhill Shales, and in one or two instances of the Hartfell Black Shales.

When the Urr is followed northwards for about a third of a mile

to a bend where a streamlet from Knocklearn Farm joins the river from the west, the Moffat Shales are seen to reappear.

Here a small exposure of Barren Mudstones is followed by black shales, which, visible at the edge of the river, contain *Climacograptus normalis*, *Diplograptus tamariscus*, *Diplograptus acuminatus* (?), and *siculae* of graptolites.

About six yards down stream on the same bank the following forms were obtained from a black shale band: *Diplograptus foliaceus*, *Climacograptus bicornis*, *Climacograptus* with three spikes, *Retiolites (Neurograptus) fibratus*, *Diplograptus quadrimucronatus*, and *Leptograptus flaccidus*. Here were found in profusion, in the black shales, arms of *Dicellograptus* and *Diplograptus socialis* (?) (Lapw.) The foregoing assemblage of fossils undoubtedly belongs to the Hartfell group.

Crossing the river and proceeding northwards along the east bank, we meet with a fine development of the Barren Mudstones and Birkhill Shales, the former occupying the core of the arch. On the south limb of the fold the Lower Birkhill Shales dip towards the north-west at high angles and have furnished the following assemblage of graptolites:

Diplograptus acuminatus (Nich.)
,, *vesiculosus* (Nich.)
,, *tamariscus* (Nich.)
Monograptus attenuatus (Hopk.)
Climacograptus normalis (Lapw.)
Dimorphograptus Swanstoni (Lapw.)
,, *elongatus* (Lapw.)

This locality is of special interest because it furnishes beautiful specimens of *Dimorphograptus Swanstoni*. The fine specimen in the Geological Survey Collection was here obtained.

On the north side of the arch the Birkhill Shales are again met with, having a general north-west dip.

The most northerly exposure of the Moffat Shales occurs at a bend on the west bank of the Urr, due west of Nether Glaisters, where the relations of these strata to other rocks are not visible. Here they enclose:

Dimorphograptus Swanstoni (Lapw.)
,, group of above.
Climacograptus normalis (Lapw.)
Diplograptus confertus (Nich.)
Monograptus Sandersoni (Lapw.)
,, *gregarius* (Lapw.)

About half a mile to the east of the river Urr at Crogo Tower, in the Auchenhay Burn, which joins the Knarie Burn, a tributary of the Urr, a small outcrop of the Birkhill Shales occurs in a wood about a quarter of a mile to the north of its junction with the Knarie Burn and below Fordhouse. The species in the following list were collected from this locality:

Monograptus Hisingeri (Carr.)
,, *cyphus* (Lapw.)
,, *leptotheca* (Lapw.)
,, *tenuis* (Portl.)
,, *lobiferus* (M'Coy.)
,, *Sedgwicki* (?) (Portl.)
,, *attenuatus* (Hopk.)
,, *gregarius* (Lapw.)
Diplograptus tamariscus (Nich.)
,, *confertus* (Lapw.)
,, *acuminatus* (?) (Nich.)
Petalograptus palmæus (Barr.)
Dimorphograptus Swanstoni (Lapw.)
Climacograptus normalis (Lapw.)
Dawsonia campanulata (Nich.)

Crogo Burn, Auchenvey.—On the west side of the Urr an important tributary of that stream, named the Crogo Burn, about two miles north-west of Corsock, shows a section of the Birkhill group. Here, at a point a few yards east of where the stream is crossed by the road from Corsock to New Galloway, the shales yield *Diplograptus confertus*, *Climacograptus normalis*, *Diplograptus vesiculosus*, *Monograptus gregarius*, *M. tenuis*, *M. attenuatus*.

Towards the north-east this axial fold is traceable at intervals for nearly a mile by means of isolated exposures; towards the south-west it can be followed for about half a mile along the east border of the Auchenvey Plantation, the Barren Mudstones appearing not far to the south-west of the New Galloway Road.

Barend and Auchenvey.—Between the valley of the Urr and Loch Ken the Moffat Shales reappear on an axial fold which extends along part of the course of the Barend Burn to the Auchenvey Hill, a distance of upwards of three miles. Like the bands previously described, the members of the Moffat series are arranged in the form of an arch or a series of compound folds, usually inverted and broken by faults. At one or two points in the course of this band the Hartfell Shales appear; there is also a fine development of the Barren Mudstones and the overlying Lower Birkhill Shales.

The best section in the course of the Barend Burn, showing the sequence from the Barren Mudstones through the Birkhill group to the overlying greywackes and shales, is to be found at a point half a mile to the north-east of the Barend Farmhouse. Here the stream, for a distance of nearly 300 yards, runs in a south-easterly direction at right angles to its normal course. For part of this distance it flows through a rocky gorge, displaying a fine section of several members of the Moffat series. Where the stream issues from the ravine the Barren Mudstones appear, having at one point a south-east dip. Ascending the gorge we find the Birkhill Shales in normal sequence on the north limb of the arch, the *D. vesiculosus* zone being at once recognised by its flaggy character, as in the Moffat region. At the waterfall the following species were collected:

Diplograptus vesiculosus abundant.
,, *tamariscus* (Nich.)
,, *confertus* (Nich.)
,, *acuminatus* (Nich.)
Dimorphograptus elongatus (Lapw.)
Dimorphograptus Swanstoni (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
Climacograptus normalis (Lapw.)

To these strata succeed alternations of black shales and grey clays; from the former were obtained fine specimens of *Rastrites peregrinus*, together with *Monograptus gregarius* and *Climacograptus normalis*. These shales pass upwards into sandy shales and greywackes. On the north limb of the fold it is evident that there is a continuous sequence from the Barren Mudstones to the greywackes and shales overlying the Birkhill Shales.

At the mouth of the gorge the section is obscured for a short distance, but at the point where the Barend Burn resumes its normal south-west course the black shales occur. To the south of the line of strike of the foregoing arch isolated exposures of the Barren Mudstones and the Birkhill Black Shales appear in the course of the stream, and in the fields towards the farmhouse of Barend. Further to the south-west, below the farmhouse, the cherts appear on the south-east bank of the burn associated with black shales, but they are so much bleached that it is difficult to determine their horizon from the fragments of graptolites obtainable from the shales.

To the north-east of the fine section in the gorge of the Barend Burn, above described, the Moffat series can be traced for about 1¼ miles to the watershed between the Barend and Auchenvey Burns, forming compound folds which reveal the Barren Mudstones and Birkhill Shales, and in some instances the Hartfell Shales.

Still further to the north-east, the Auchenvey Burn presents an interesting, though not continuous, section of the Birkhill and Hartfell Black Shales. At the ford, where a hill path crosses the stream, an exposure of Hartfell Shales has yielded *Retiolites (Neurograptus) fibratus*, *Dicellograptus Forchhammeri*, *D. Morrisi*, *D. elegans*, *Leptograptus flaccidus*, *Climacograptus*, *Diplograptus foliaceus*.

Down stream towards the south-east there is a blank in the section, but towards the north-east, along the strike of the beds, the Barren Mudstones appear at no great distance from the burn. On the south-east limb of the fold the Birkhill Shales are visible on the east bank, where they are brought into contact with the greywackes by means of a fault. On the north-west side of the arch the Birkhill Shales reappear and yield the following forms: *Monograptus gregarius*, *M. tenuis*, *Diplograptus vesiculosus*, *Climacograptus normalis*, and *sicula* of graptolites.

To the north-east, on the Auchenvey Hill, the prolongations of the band above described reappear. At one point on the hill-top blocks of radiolarian chert can be traced along the line of strike, evidently indicating that the chert zone is there *in situ*. To the north and south of this band the Moffat series comes to the surface along several folds, representing the Hartfell Shales, Barren Mudstones, and Birkhill group.

We must now refer to certain exposures of the Moffat series where the strata having either not yielded graptolites at all or only indeterminable fragments, their horizon cannot be definitely determined by palæontological evidence. But as they occur within the area of the Tarannon Rocks they may with probability be referred, in part at least, to the Birkhill group. One of these exposures occurs by the side of the road near Barlay, about 2½ miles E.S.E. of Balmaclellan. Others may be seen on the Benan Hill within the contact zone of the New Galloway mass of granite. Others, likewise within the contact zone, in the

Knocknairling Burn and on the Knocknairling Hill, are traceable to the granite junction.

Glen Burn and Skeoch.—In the south-east part of Sheet 9 of the Geological Survey Map an important band of the Moffat series appears in the Scar Burn, near Skeoch Farmhouse, and can be traced still further to the south-west along the course of the Glen Burn for upwards of a mile.

In the Scar Burn, about a quarter of a mile west of Skeoch Farmhouse and about half a mile up stream from the point where it joins the Old Water, the black shales crop out. Further down the stream brown flags and shales, with occasional greywackes, dip towards the north-west at high angles. These are underlain by blue, grey, and black shales alternating with grey clays, which have yielded *Climacograptus normalis*, *Monograptus gregarius*, *M. Sandersoni*, *M. leptotheca*, *M. tenuis*, *Dimorphograptus Swanstoni*, *Dawsonia campanulata*. A few yards down stream on the east bank flaggy black shales occur of the *D. vesiculosus* zone, which yielded *D. vesiculosus*, *Dimorphograptus elongatus*, *Monograptus tenuis*, *Diplograptus tamariscus*.

These strata are followed still further down stream by the Barren Mudstones, when a blank occurs in the section, the strata next met with being grey flags and shales.

Glen Burn.—Ascending this stream to a point about 500 yards west from Glen Burn (Fig. 31), black shales are found in the channel of the burn and on the north-west bank, from which the following assemblage of fossils has been collected: *Leptograptus capillaris*, *Pleurograptus linearis*, *Climacograptus*, *Dicellograptus*, *Diplograptus foliaceus*, &c. South of this exposure a fine development of Barren Mudstones occupies the burn section for a distance of about 100 yards, followed by black shales, probably on the horizon of the Lower Birkhill division, though no fossils were obtained to prove their position. Still further west the Barren Mudstones reappear, and are succeeded on the south limb of the fold by the Lower Birkhill Shales, yielding *Diplograptus acuminatus*, *D. vesiculosus*, *Dimorphograptus elongatus*, *Climacograptus normalis*, &c. Thereafter the stream traverses the overlying greywackes and shales for several hundred yards as far as the margin of the Glen Plantation, but the arch in the Moffat series can be traced along the northern bank. In the plantation, the observer can trace the arch in the Moffat series for a distance of about 700 yards. As the course of the stream is more westerly, he soon reaches the Birkhill Shales exposed on the south limb of the fold, where they furnish specimens of *Dimorphograptus*, *Diplograptus vesiculosus*, *D. tamariscus*, *Climacograptus normalis*, *Monograptus tenuis*, *M. attenuatus*. For some distance up stream the centre of the fold is occupied by the Barren Mudstones, while the overlying Birkhill Shales are exposed on both limbs at occasional bends in the stream-course. At a point in the wood S.S.E. of Glen Farmhouse, and about 200 yards east from the west margin of the wood, black shales appear on the south-east bank associated with radiolarian cherts and ashy mudstones. From the following list of

fossils obtained from this locality it is evident that the strata represent the Glenkiln Shales:

Thamnograptus, sp.
Cœnograptus pertenuis (Lapw.)
Leptograptus flaccidus (Hall.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus formosus (Hopk.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *patulosus* (Lapw.)
Climacograptus peltifer (Lapw.)
Diplograptus foliaceus (Murch.)
Siphonotreta micula (M'Coy.)

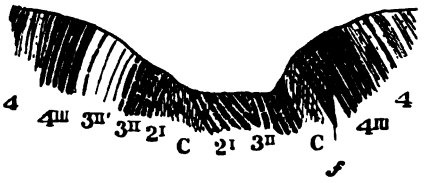


FIG. 31.—Section across Glen Burn, near Glen Farm, north-east of Kirkcudbrightshire.

C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3ll'. Barren Mudstones. 4lll. Birkhill Shales. 4. Greywacke and shale (Llandovery-Tarannon). f. Fault.

For a short distance westwards the radiolarian cherts and ashy mudstones appear at intervals. Leaving the plantation and crossing the alluvial flat S.S.W. of Glen Farmhouse, the observer will notice another exposure of the Arenig cherts and spotted ashy mudstones or tuffs resembling those south of Trowdale Wood in the valley of the Urr. Further to the south-west, in the direction of Larghill Bridge, the Arenig cherts and ashy mudstones can be traced on the rising ground south of the road, and the black shales associated with them are visible in a quarry at the road-side. Near Larghill Bridge, in a little tributary of the Brooklands Burn, south of the road, black shales appear on both sides of an arch of Arenig cherts and volcanic tuffs about 100 yards broad. The black shales are much crushed, but those on the north side of the anticline have yielded *Climacograptus caudatus*, *Dicellograptus moffatensis*, *D. flexuosus*, *Diplograptus foliaceus*—forms which evidently indicate a Hartfell horizon. The Arenig cherts are visible west of Larghill Bridge, but the strata are buried in this direction under a covering of drift and peat.

Trowdale, Crossmichael, and Lawrieston.—Along a line extending from Tottlehams Burn and Trowdale Glen by Crossmichael to Lawrieston, exposures of the Moffat series may be observed (Sheet 5 of Survey Map). Though nearly in the same line of strike, these outcrops occur on separate folds. The most important of them are those of Trowdale Glen, Tottlehams Burn, and adjoining fields, in the valley of the Urr, about four miles north of Castle-Douglas, which will be first described.

On the west bank of the Urr, in the fields immediately to the south of Trowdale Glen, the lowest beds are exposed. These

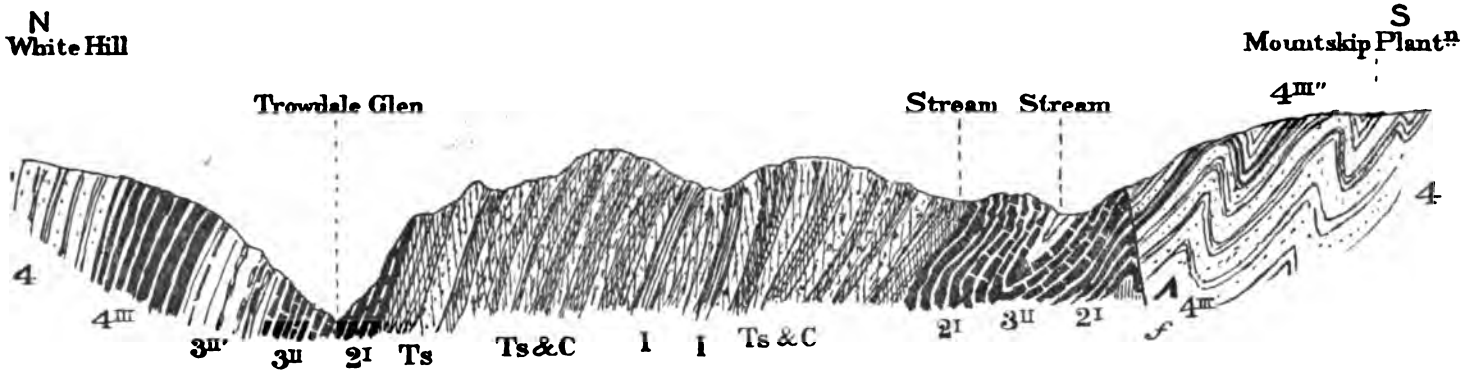


FIG. 32.—Section across Trowdale Glen, Water of Urr, Stewartry of Kirkcudbright. (Length, half a mile.)

Ts Volcanic tuff. C. Radiolarian chert. 1. Arenig? 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3ll′. Barren Mudstones. 4lll. Birkhill Shales. 4lll″. *Exiguus*-zone 4. Tarannon series. f. Fault.

consist of radiolarian cherts, mudstones, and shales, associated with fine felsitic tuff. They are inclined to the north-west at high angles, and plunge underneath the band of Glenkiln-Hartfell black shales exposed in the Trowdale Glen. There is one peculiar band of shales, which breaks under the hammer into pencil-shaped fragments, exposed in a small hollow about 120 yards to the south of Trowdale Glen in the midst of ashy mudstones and cherts. It is highly probable that this band and others associated with it may yield Arenig graptolites, though a careful search has hitherto failed to bring them to light. The volcanic tuff is well seen in knolls close to Trowdale Wood, and it likewise forms a prominent feature in the wood to the south of the Glenkiln black shales. The lithological character of this rock is interesting. The common variety is a dull pinkish-grey rock, which on weathered surfaces has a yellowish tint. It has a curious speckled appearance owing to the presence of pink or yellow spots in a grey matrix. Sometimes the rock is compact, has a uniform colour, and breaks with a conchoidal fracture.

The intercalation of some of these felsitic tuffs between the Glenkiln black shales and the radiolarian cherts seems to indicate the continuance of volcanic conditions in that area in Llandeilo time. Abundant evidence has been obtained of similar phenomena during the re-examination of the volcanic area south of Ballantrae.

In the section in Trowdale Glen (Fig. 32), the Glenkiln black shales occur near the entrance, and may be followed along the south bank for a short distance up stream. They consist of black flinty ribs, with black shale partings, passing upwards into the Hartfell black shales, which are in turn overlain by the Barren Mudstones, forming the north cliff in the lower part of the glen. The black shales in the ravine have yielded the following fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *nitidulus* (Lapw.)
,, *pertenuis* (Lapw.)
Diplograptus Whitfieldi (Hall.)
,, *foliaceus* (Murch.)
Clathrograptus cuneiformis (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus cælatus var. *antiquus* (Lapw.)
,, *bicornis* (Hall.)
Dicellograptus patulosus (Lapw.)
,, *moffatensis* (Carr.)

The Birkhill Shales are not visible in the Trowdale Glen to the north of the Barren Mudstones, but a small exposure of them is seen on a footpath about half a mile east of Balgerran Farm-house, in the strike of the Trowdale band, which has yielded fragments of *Dimorphograptus*.

From the foregoing description it is apparent that the strata in the neighbourhood of Trowdale form the northern limb of a fold, the lowest beds being the radiolarian cherts and volcanic tuffs, and the highest, some member of the Birkhill black shales. Southwards towards the Mountskip Plantation, however, the relations of the strata are disturbed by faults. The southern

limb of the fold cannot be traced. Greywackes of Tarannon age rapidly follow the cherts in the field to the south of Trowdale Glen, and are also visible in a burn in the Mountskip Wood. It is clear that a fault must intervene to bring these different zones in contact with each other. Again, in the burn in this plantation, about 200 yards west from the Castle-Douglas Road, a small exposure of black shales has supplied the following Glenkiln forms:

Didymograptus superstes (Lapw.)	*Dicellograptus moffatensis* (Carr.)
Lasiograptus bimucronatus (Nich.)	,, *patulosus* (Lapw.)
Cryptograptus tricornis (Carr.)	,, *divaricatus* (Hall.)

The relations of these shales to the surrounding rocks are not visible. Above the forkings of this burn, in the south branch, the Barren Mudstones are met with; but this exposure is also isolated. The nearest visible rocks consist of Tarannon greywackes and shales, the horizon of which is clearly defined by certain fossils found in a small quarry on the north side of Mountskip Plantation, and about 500 yards south of Trowdale Glen. Here a dark band yielded the following forms:

Aptychopsis minus (Barr.)	*Monograptus turriculatus* (Barr.)
Petalograptus palmæus (Barr.)	,, *tenuis* (Portl.)
Monograptus exiguus (Nich.)	,, *attenuatus* (Hopk.)

The presence of *Monograptus exiguus* and some of its associates indicates a higher horizon than the *Rastrites maximus* band at the top of the Birkhill group.

Tottlehams Burn.—In the extension of this band in a north-east direction, the radiolarian cherts and mudstones are not visible in the Urr, owing to the alluvial covering (Sheet 5 of Survey Map). But at the mouth of the Tottlehams Burn a

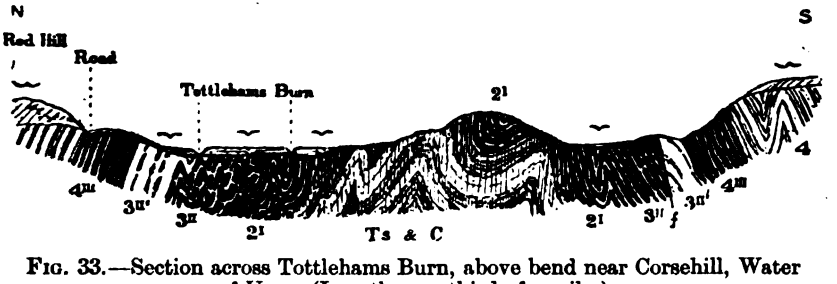


FIG. 33.—Section across Tottlehams Burn, above bend near Corsehill, Water of Urr. (Length, one-third of a mile.)

Ts. Volcanic tuff. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3ll'. Barren Mudstones. 4lll. Birkhill Shales. 4. Greywacke and shale (Llandovery-Tarannon). f. Fault. ⌒ Boulder clay. ~ Recent alluvium.

fine exposure of the Barren Mudstones may be seen in the river. A few yards below the junction of this stream with the Urr, a band of black shales, yielding *Climacograptus Schärenbergi*, *Dicranograptus*, &c., occurs in the mudstones, possibly repre-

senting a part of the Hartfell black shales in an isoclinal fold. There the strata dip in a uniform direction towards the north-west at high angles.

In the Tottlehams Burn the Barren Mudstones present the characteristic features of the zone. They contain nodules composed of oxides of iron and manganese, the latter ore predominating. From an examination of one of the cores of these nodules by Mr. Teall, it appears that it is a carbonate of manganese and iron. It is traversed by a vein, black in the middle, brown at the margins, fading off gradually into the surrounding rock. There are also peculiar structures, probably organic, in this rock. From these data he infers that the rock was originally a limestone, that it was subsequently changed to a carbonate of manganese and iron, and finally that the carbonate was decomposed under oxidising conditions so as to give rise to the nodular masses of the oxides of the two metals.

At the mill, alongside of the public road, the Glenkiln-Hartfell black shales appear in the burn and the mill-lead, rising from underneath the Barren Mudstones. The following fossils characteristic of these groups were here obtained:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Didymograptus superstes (Lapw.)
Diplograptus foliaceus (Murch.)
Climacograptus Schärenbergi (Lapw.)
Climacograptus caudatus (Lapw.)
Retiolites (Neurograptus) fibratus (Lapw.)
Dicellograptus Forchhammeri (Geinitz.)

The Barren Mudstones are seen in the mill-lead for about 80 yards above the mill. From the mill pond, for a distance of 500 yards up stream, the rocks are concealed by boulder clay; but at the eastern edge of the Tottlehams Wood, the Barren Mudstones appear on the south bank of the stream, succeeded on the south by a small exposure of the Birkhill Shales, which contain, amongst other forms, *Diplograptus acuminatus*, *Climacograptus normalis*, &c. On the north-east side of the stone fence crossing the burn at the point where the stream-course changes and bends towards the north, a small exposure may be seen of black shales charged with *Climacograptus caudatus*, *Diplograptus*, and *Dicellograptus moffatensis*, characteristic of the Lower Hartfell group. They are followed by Tarannon greywackes to the south, so that a fault must here come between these zones. They must be truncated also by a north and south fault, which brings them in contact with the Barren Mudstones and Birkhill Shales just described.

From the prominent bend in the Tottlehams Burn just referred to, north-eastwards by Corsehill and Barmofitty, the members of the Moffat series are traceable for a distance of about half a mile, partly by means of rocky knolls peering through the drift. The bands of felsitic tuff with cherts and mudstones inclined to the north-west at high angles can be followed in isolated exposures to the fields west of Barmofitty Farmhouse. On the north side they are succeeded by the Glenkiln-Hartfell black shales visible in the

Tottlehams Burn and in the fields south-west of Corsehill. On the south side of the fold black shales are well exposed on a knoll about 150 yards north of the east end of Tottlehams Wood, with graptolites of the Glenkiln horizon, in abundance and excellent preservation. Here the black shales are repeated by folds, and the grey radiolarian cherts are brought to the surface in two sharp anticlines. The following fossils were here collected (Fig. 33):

Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
,, *pertenuis* (Lapw.)
,, *nitidulus* (Lapw.)
Didymograptus superstes (Lapw.)
,, *serratulus* (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *mucronatus* (Hall.)
,, *Whitfieldi* (Hall.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
,, *cælatus* var. *antiquus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *divaricatus* (Hall.)
,, *moffatensis* (Carr.)
Dicranograptus tardiusculus (Lapw.)
,, *ramosus* (Hall.)
Clathrograptus cuneiformis (Lapw.)
Siphonotreta micula (M'Coy.)

In the prolongation of the Trowdale band in a south-westerly direction towards Kilnotrie and Crossmichael, only isolated exposures of the Moffat series protrude through drift. Along the strike of the outcrops south of Trowdale Glen, the radiolarian cherts, mudstones, shales, and volcanic tuffs are met with in fields about a third of a mile south-east of Balgerran Farmhouse, the general dip being to the north-west. On the north side of the fold these strata are succeeded by the Glenkiln-Hartfell shales, which, at an old mine about one-third of a mile E.S.E. of Balgerran, have yielded: *Cœnograptus gracilis*, *Clathrograptus cuneiformis*, *Climacograptus bicornis*, *C. cælatus* var. *antiquus*, *Diplograptus foliaceus*, *Dicellograptus moffatensis*, *Siphonotreta micula*.

Again, on the south side of the cherts and mudstones, in a field north-west of Mountskip Plantation, and not far to the north of the *Monograptus exiguus* band already referred to, soft black shales, which appear at the side of a streamlet, have supplied some characteristic Glenkiln forms, with others (Fig. 32):

Didymograptus superstes (Lapw.)
,, nov. sp. with disc.
Cœnograptus gracilis (Hall.)
Thamnograptus typus (Hall.)
Diplograptus euglyphus (Lapw.)
,, *Whitfieldi* (Hall.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *cælatus* var. *antiquus* (Lapw.)
Glossograptus Hincksi (Hopk.)

In consequence of a synclinal fold the Barren Mudstones appear to the south of this exposure, followed by the Glenkiln shales, charged with *Cœnograptus gracilis*, *Diplograptus Whitfieldi*, *D. foliaceus*, *Climacograptus bicornis*, *Dicellograptus*, *Lasiograptus bimucronatus*, &c.

Westwards, at the Kilnotrie Farmhouse, the cherts and volcanic tuffs crop out in the fields to the north of the steading, and may be followed west to a point south of Erncrogo Loch. They occur on a different anticlinal fold from that of the Trowdale band, though

not far to the south of it. The Glenkiln-Hartfell black shales and Barren Mudstones occur on the north side of the anticline in the fields near Erncrogo Loch, and on the south side of the fields to the east of Kilnotrie. A few yards west of Kilnotrie Farmhouse the following Hartfell species were obtained: *Climacograptus caudatus, C. bicornis, Diplograptus foliaceus, D. tricornis, Dicellograptus moffatensis.* Again, at Crossmichael the black shales are visible near the south end of the village, while the felsitic tuffs appear on the slope north-east of this locality, but their relations to the surrounding rocks are not apparent.

Still further to the south-west, in the neighbourhood of Lawrieston, the volcanic tuffs and radiolarian cherts are to be seen at one or two localities, south of Bellymack Farmhouse, and about half a mile east of the village. Here they are associated with black shales, visible in a small burn east of South Quintenespie, charged with *Didymograptus superstes, Lasiograptus bimucronatus, Cryptograptus tricornis, Climacograptus bicornis, Dicellograptus moffatensis, D. Forchhammeri,* &c. The black shales likewise appear at the roadside a few yards west of Bellymack.

About a mile to the south-west of the last-named locality, representatives of the Birkhill black shales come to the surface along an axial fold in the Tarannon greywackes and shales. From the assemblage of their fossils, it is apparent that members of the Lower Birkhill division are here met with, ranging from the *Diplograptus acuminatus* zone to that of *Monograptus gregarius.* In the stream, about fifty yards to the north of Dunnance Farmhouse, black shales are exposed, dipping to the north-west, from which the following fossils were obtained:

Diplograptus acuminatus (Nich.)
,, *vesiculosus* (Nich.)
Climacograptus normalis (Lapw.)
Dimorphograptus (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *lobiferus* (M'Coy.)
Dawsonia campanulata (Nich.)

In one of the branches of this stream, about one-third of a mile south-west of Dunnance Farmhouse, in the same line of strike, the black shales yielded:

Diplograptus acuminatus (Nich.)
,, *tamariscus* (Nich.)
Climacograptus normalis (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *leptotheca* (Lapw.)
Monograptus jaculum (Carr.)
,, *triangulatus* (Hark.)
,, *gregarius* (Lapw.)
,, *lobiferus* (M'Coy.)
Lingula striata (Sow.)

At this part of the stream-section the black shales are repeated several times by isoclinal folds inclined to the N.N.W. in conjunction with the Llandovery grits and shales.

Hensol Black Shale Band, River Dee.—Owing to plications of the overlying Tarannon grits and shales, the members of the Moffat series reappear about three miles to the north of the Lawrieston band, in the River Dee at Hensol House, close to its junction with the Ken. This exposure is of special interest, as the strata are arranged on the whole in a normal fold,

the lowest beds occupying the core of the arch. On the north bank of the river, at the bend a quarter of a mile below Hensol House, Barren Mudstones form the centre of the fold, succeeded on both sides by the Lower Birkhill Shales. At the top of the Barren Mudstones, on the south side of the arch, *Dicellograptus anceps* was obtained from black shales that have here been pierced by an intrusive dyke. A band of black grits is, on the south limb of the arch, associated with the Birkhill Shales, which are inclined to the south-east at high angles. In like manner, the Lower Birkhill zones dip away from the Barren Mudstones on the north side of the fold. The Birkhill Shales have here yielded the following forms:

Diplograptus vesiculosus (Nich.)
,, *tamariscus* (Nich.)
Dimorphograptus elongatus (Lapw.)
Climacograptus normalis (Lapw.)
Monograptus tenuis (Portl.)
,, *attenuatus* (Hopk.)
,, *gregarius* (Lapw.)
Dawsonia campanulata (Nich.)

It is worthy of note that the highest zone represented here is that of *Monograptus gregarius*, as the Llandovery greywackes and shales immediately succeed in the railway cutting to the north. These members of the Moffat series can be traced down the river Dee for a short distance along the strike, and they are also visible in the railway cutting to the north. A small exposure of the Birkhill Shales occurs on another fold near the railway viaduct on the east bank of the Ken.

Not far from the granite boundary, in the north-west corner of the map, two outcrops of black shales may be observed, one on the south slope of Benan Hill, south of Loch Stroan, and the other in Clenoch Burn. A third exposure is seen in the Castramont Burn about two miles from the granite margin. In these instances, the Moffat Shales come to the surface along isoclinal folds, inclined to the south-east, but the beds are too much altered to yield graptolites.

Barlay Burn.—About two miles to the north-east of Gatehouse, at a marked bend in the Barlay Burn, representatives of the Lower Birkhill group appear, much contorted and traversed by faults. At the first exposure, in the ascent of the burn, the black shales are cleaved and corrugated, dipping to the south-east at low angles. Here they have yielded specimens of *Climacograptus normalis*. A few feet above this outcrop, thin bands of black shales with seams of white clay occur, from which have been obtained *Monograptus triangulatus*, *M. tenuis*, *M. lobiferus*, and *Climacograptus normalis*. These are overlain by grey shales. A fault running in a north-west and south-east direction bounds these beds on the west side, bringing them into conjunction with grey greywackes. Further up stream the band is traversed by two faults, but the shales are traceable as far as the bridge across the burn. A thin band at this north-east exposure yielded *Diplograptus acuminatus*, *D. tamariscus*, *Monograptus tenuis*, &c. Near the bridge, *Monograptus gregarius* and some of its associates were found.

Coal Heugh.—In this small tributary of the Tarff Water, and also in the Tarff section, the Birkhill Shales are visible on another fold. Indeed, the Coal Heugh receives its name from this outcrop of black shales, which led to excavations in search of coal. Ascending the Tarff from Ringford, we find brown-crusted flags, blue shales, and fine-grained greywackes, inclined to the north-west. On the west bank of the Tarff, opposite Liggatcheek, and near the mouth of Coal Heugh, shattery green shales, flags, and jointed greywackes veined with calcite appear. These are succeeded by grey shaly clays and thin bands of black shale. They are prolonged up the Coal Heugh, the best exposure being at the site of an old mine. The beds are much slickensided, and fossils are difficult to obtain, but specimens of *Diplograptus acuminatus* and *Climacograptus normalis* were here collected.

From the evidence adduced in the foregoing pages, it appears that the highest zone of the Moffat series in the district between the Nith and the Fleet is that of *Monograptus gregarius*. The Moffat type of the Upper Birkhill division has not as yet been detected in this area. It is probably represented by some of the coarser sediments. The occurrence of *Monograptus Sedgwicki* (Portl.) in a dark seam interleaved in greywackes and shales in the Tarff Water west of Upper Lairdmannoch seems to support this conclusion.

Black Shale Bands near the South-west Margin of the Cairnsmore of Fleet Granite Mass.—Along the southern margin of the granite mass of Cairnsmore of Fleet between Little Water of Fleet and Creetown Station, and again along the western edge of the granite, there are various outcrops of the Moffat Shales appearing along sharp anticlinal folds. In this district the black shales, after passing from black to blue and dull grey, have been so much hardened and altered as to have become schistose and to have lost all traces of the original bedding. When in this altered schistose condition, they become remarkably tough, generally split up into large square blocks, and usually contain various contact minerals. No traces of graptolites have been observed in the more highly altered bands; near Palnure Station, however, graptolites are recognisable, but too imperfect for identification.

River Cree, One Mile North of Newton-Stewart.—About a mile to the north of the Bridge of Cree at Newton-Stewart the Glenkiln-Hartfell black shales and Barren Mudstones come to the surface in the midst of greywackes and shales. From evidence obtained near Glenluce it is probable that the latter sediments are of Llandovery age, though no Birkhill Shales are visible in this section. The members of the Moffat series appear about half a mile above the junction of the Cree with the Penkill Burn, at a point where the Cree flows for 200 yards in an E.N.E. direction. On the north bank of the stream at this bend the Glenkiln-Hartfell black shales are visible, and have there yielded *Diplograptus foliaceus*, *Climacograptus*, &c. This outcrop crosses

the Cree to the west bank, and is followed on the south limb of the fold by a fine development of the Barren Mudstones, of the type so characteristic of the central Moffat region, and these in turn are succeeded by thick grits. Northwards the Hartfell Shales are succeeded by Barren Mudstones, rolling about at low angles and forming flat arches. The Hartfell Shales reappear, however, on a second anticline about fifty yards north of the main exposure, and yield certain forms characteristic of the *Pleurograptus linearis* zone, viz.: *Diplograptus quadrimucronatus*, *Dicellograptus Morrisi*, *Climacograptus*. Again, the Barren Mudstones reappear to the north of this latter exposure and occupy the stream for a distance of 120 yards, where they are followed by massive grits and shales which dip southwards, and are thus inverted, at high angles. A careful search for graptolites was made in the shaly bands at the base of the grits, but without success.

Following the Cree southwards from the main outcrop of Hartfell Shales at the prominent bend in the river, the observer finds two arches of the Barren Mudstones ere he reaches the point of junction between the Cree and Penkill Burn, the more northerly of the two having a thin core of black shales. The black shales and Barren Mudstones appear in the Penkill Burn to the north-east of these arches. About a mile and a half up this tributary of the Cree, near the footbridge leading to Cumlodden School, much contorted and crushed black shales yielded *Climacograptus*, *Diplograptus*, and *Dicellograptus*, thus indicating a Glenkiln-Hartfell horizon. This band of shale stretches for some distance to the E.N.E., but owing to the contact metamorphism induced by the Cairnsmore of Fleet granite, its horizon cannot be fixed by fossil evidence. At the band of the Well Burn, Talnotry, and about 300 yards N.N.W. from Talnotry, the altered black shales were mined for plumbago on the outcrop of the Drumlawhinnie and Loch of the Lowes band.

CHAPTER IX.

THE CENTRAL BELT—*continued.*

BLACK SHALE BANDS BETWEEN THE CREE AND THE MULL OF GALLOWAY.

In the broad belt of Tarannon Rocks stretching from the mouth of the Cree across the low grounds of Wigtownshire to the shores of Luce Bay, the representatives of the Moffat series come to the surface along various anticlines. Of these, the most important is the series of bands that extend from Drumblair by Glenling and Crailloch to Ballaird.[1] (Sheet 4 of Survey Map.)

Glenling, Crailloch, and Ballaird Black Shale Bands.—This series of outcrops is traceable from Drumblair, on the east shore of Luce Bay, 5½ miles N.W. of Port-William, to Ballaird, 5 miles W. from the mouth of the river Bladenoch. Near the western termination of the bands, the radiolarian cherts are visible at three localities, and from this horizon there is an ascending sequence to the *M. gregarius* zone. The outcrops of the black shales are extremely irregular; there are no continuous cross-sections in streams, the exposures being met with in fields and on moorland.

Drumblair.—The section on the hill-face north of Drumblair shows grey, massive, and nodular radiolarian cherts, some of the beds measuring two feet thick. In the core of the arch there is a fine-grained felsitic rock which may probably represent some member of the Arenig volcanic series. The cherts are visible in a knoll in the field, but their relations to the surrounding rocks are not visible. A few yards to the north, debris of black shales is seen, and still further north greywackes appear. To the south of these radiolarian cherts the black shales appear at Drumblair, and in the road leading to the house. They are visible at various localities in the neighbourhood of Drumblair, but the horizon of these shales has not been proved.

Garheugh.—The by-road leading to Garheugh from the main road at Altlcry, half a mile west of Drumblair, furnishes sections of the members of the Moffat series (Fig. 34). About 300 yards north of the main road the cherts appear, with the black shales on both sides. On the north limb of the fold, and in the field adjoining the road to the east, the following forms were obtained: *Climacograptus bicornis*, *C. tridentatus*, *Cryptograptus tricornis*, and *Diplograptus foliaceus*.

For a short distance there is a blank in the road section, but to the northwards an exposure of black shales yields *Diplograptus*

foliaceus, *Dicellograptus*, and *Climacograptus*. Next we find, for about 30 yards, the Barren Mudstones, which are succeeded by the Birkhill Shales. It is probable that the whole sequence of the Lower Birkhill group is here represented, but the only fossils obtained belong to the *M. gregarius* zone, as given in the following list:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *leptotheca* (Lapw.)
,, *Hisingeri* (Carr.)
Diplograptus tamariscus (Nich.)
Climacograptus normalis (Lapw.)
Dawsonia campanulata (Nich.)

FIG. 34.—Generalised Section from Garheugh to Alticry, east side of Luce Bay, Wigtownshire.

C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3ll'. Barren Mudstones. 4lll. Lower Birkhill Shales. 4. Greywacke and shale (Llandovery). f. Fault.

The Barren Mudstones come to the surface at the roadside for a distance of 30 or 40 yards, while in a quarry at a sharp bend in the road, 200 yards from Garheugh, a thin seam of black shales has yielded *Diplograptus foliaceus*. This outcrop of Barren Mudstones, after crossing a narrow hollow, is succeeded by grits and greywackes, the latter being probably brought into conjunction with the Moffat series by means of a fault. This hollow runs in a north-east direction by the Black Loch, and is bounded on the north by a line of cliff composed of grits, greywackes, and shales. The probable fault-line is oblique both to the Moffat series and to the greywackes and shales to the north. North-eastwards along the hollow occupied by the fault, within 100 yards of the quarry just described, a cliff of greywacke rises on the north side of the feature and the black shales appear on the south side. These shales here form one limb of an arch, and dip generally to the south about 70°, the lowest zone occurring nearest the fault. The Barren Mudstones are seen at the base of the slope underneath the black shales with a south-east dip, followed by the *Diplograptus acuminatus* zone. This outcrop of the Moffat series can be traced north-eastwards by the Black Loch for two-thirds of a mile. At a point about 300 yards south-west from the Black Loch, the black shales contain *Diplograptus vesiculosus*, *D. tamariscus*, *Dimorphograptus elongatus*, *Climacograptus normalis*, and *Monograptus*. On the south bank of the Black Loch the following forms were obtained: *Diplograptus acuminatus*, *Monograptus attenuatus*, *Climacograptus* sp., and *sicula* of graptolites. Not far to the north-east of the Black Loch the foregoing band of black shales is truncated by the fault already referred to, the overlying greywackes and shales appearing along the strike to the north-east (Fig. 35.)

Near Loch Doon, about 300 yards E.S.E. of the Black Loch, there is a nearly parallel fold of black shales which has been traced for a distance of two-thirds of a mile, with the Barren Mudstones in the centre and the Birkhill Shales on both sides (Fig. 35).

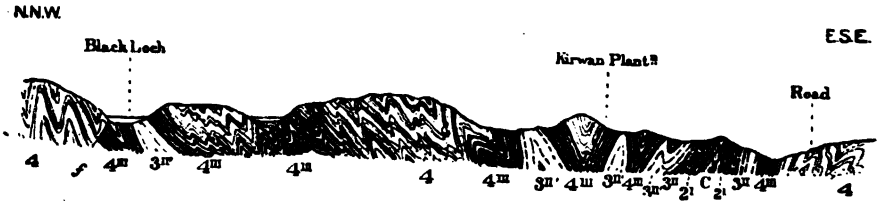


FIG. 35.—Generalised Section across the Black Loch and Kirwan Plantation to Drumblair, east side of Luce Bay, Wigtownshire.

(For explanation, see Fig. 34.)

The folds of the Moffat series, forming numerous though isolated exposures between Drumblair and the Black Loch, as already described, disappear within half a mile to the north-east of Drumblair, and are succeeded by the overlying greywackes and shales. Along the line of the two most northerly folds (Black Loch and Loch Doon bands) the Moffat Shales have not been observed on the Drumblair Moor to the north-east. To the south-east, however, the Moffat series reappears near Kirwan Plantation (Fig. 35). From this point to the road near the farmhouse of May—a distance of about a mile—the members of this series occupy a belt of ground about a quarter of a mile wide. The exposures are confined chiefly to the cultivated ground and the rocky knolls scattered through the fields. The evidence is, therefore, imperfect, and, indeed, we seldom find here two of the main groups of the Moffat series in conjunction. The lowest beds exposed are the radiolarian cherts, which occupy the crest of a small knoll in a field about half a mile W.S.W. of May Farmhouse and about 100 yards from the public road. The cherts are here followed by black shales, from which the following forms have been collected: *Diplograptus foliaceus*, *Cryptograptus tricornis*, *Climacograptus bicornis*, and *Dicellograptus*. The grey Barren Mudstones form the main portion of the rock exposures, and indeed it is highly probable that they underlie a large part of the narrow belt, from the abundance of mudstone debris in the cultivated soil between the knolls of rock.

May Farmhouse.—The Birkhill Shales are also exposed in numerous places, and often enclose boat-shaped masses of greywacke, which form the most prominent rock-knolls. At two localities on the public road, from 150 to 200 yards north-east of May, these beds have supplied *Monograptus gregarius* and *Monograptus attenuatus*, indicating that the *M. gregarius* zone is represented. Following this line of outcrop eastwards from May Farmhouse as far as the Water of Malzie, we find numerous exposures of the Moffat series covering an area about half a mile wide.

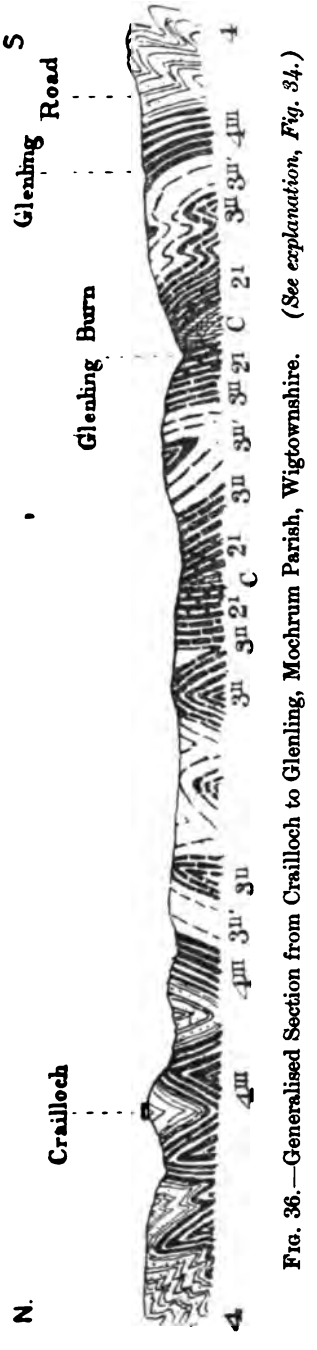


Fig. 36.—Generalised Section from Crailloch to Glenling, Mochrum Parish, Wigtownshire. (*See explanation, Fig. 34.*)

These exposures are isolated, and the evidence is more defective than in the area above described. Notwithstanding this fact, there is confirmatory evidence of the rapid plication of the Moffat series. About 500 yards east of May Farmhouse the black shales have supplied the following Birkhill forms: *Monograptus*, *Dimorphograptus*, and *Climacograptus normalis*. The Glenkiln-Hartfell Shales are exposed in a ditch about 100 yards north of Culshabben School, and about a mile further to the north-east the radiolarian cherts appear on a knoll on the west bank of the Water of Malzie, where it takes a sudden bend to the east. Indeed, along the belt of ground north of the road between Culshabben and the Water of Malzie, debris of black shales and Barren Mudstones is exposed in the cultivated ground, while occasional rocky knolls, formed of grit, project here and there through the surrounding tilled patches.

Crailloch and Low Glenling.—About four miles inland from the east coast of Luce Bay the neighbourhood of Crailloch and White Dyke is occupied chiefly by peat mosses, with intervening cultivated knolls. Recently the Water of Malzie and its tributaries have been artificially deepened, and where the cuttings exposed the Moffat series, numerous graptolites have been obtained from the Glenkiln-Hartfell and Birkhill Shales respectively.

One of the best exposures in the area is seen on the south of the Water of Malzie, on the by-road to Crailloch Farmhouse, which branches from the main road half a mile west of Low Glenling (Fig. 36). Here the radiolarian cherts appear in the bank on the south side of the road, and are succeeded by a mass of black shales which contain the following Glenkiln forms: *Diplograptus euglyphus*, *Leptograptus flaccidus*, *Dicranograptus formosus*, *Dicellograptus*, and

Climacograptus. These strata are followed by debris of platy black shales, crowded with *Leptograptus flaccidus* and *Dicellograptus*, together with *Diplograptus foliaceus* and *Dicranograptus ramosus*, probably representing a portion of the *D. Clingani* zone of the Lower Hartfell black shales.

A few yards to the north, where a cutting has been made in these Moffat Shale beds for the purpose of deepening the river, a search was made in the debris thrown out from the river bed, and the following typical Glenkiln forms were obtained, chiefly from large slabs of a dark coarse-grained shale :

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Didymograptus superstes (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Thamnograptus scoticus (Lapw.)
Climacograptus bicornis (Hall.)
,, *cælatus* var. *antiquus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *intortus* (Lapw.)
,, *patulosus* (Lapw.)
,, *moffatensis* (Carr.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)

In certain seams the *Cœnograpti* occur in great abundance; *Didymograptus superstes* is very plentiful, and the specimens of *Lasiograptus bimucronatus* are remarkably well preserved. Though the road-cutting does not expose the black shales on the north limb of the fold of radiolarian cherts, yet by following the river course westwards, debris of Glenkiln-Hartfell Shales may be observed, which may be regarded as evidence that the sequence on the north limb extends to the horizon of the Lower Hartfell group.

South from the road-cutting, the Barren Mudstones are observable at intervals at the roadside. Near the main road there is a small exposure of black shales in a quarry, and debris of black shales occurs along a footpath running west from the road. These strata are followed southwards by greywackes.

To the east of the artificial cuttings in the Water of Malzie and adjoining road, the lower members of the Moffat series extend along the river as far as a point north of Low Glenling, a distance of three-quarters of a mile. The same shales and overlying Barren Mudstones are likewise exposed in the knolls that rise out of the peaty flat through which the stream flows. In a knoll 600 yards north of Low Glenling, the Barren Mudstones are succeeded on their northern edge by a black shale containing *Rastrites peregrinus*, *Monograptus spiralis*, *M. Sandersoni*, *Climacograptus normalis*, and *Diplograptus* sp. This assemblage indicates the occurrence of the *Monograptus gregarius* zone, and perhaps a part also of a higher zone.

In the fields to the south of Crailloch, and in quarries by the side of the road from Crailloch eastwards to the Water of Malzie, the Barren Mudstones and black shales belonging to the Glenkiln-Hartfell divisions are exposed. Round Crailloch Farmhouse, and for some distance along the strike to the N.E. and S.W., the Birkhill Shales appear. At a point 300 yards

E.N.E. from Crailloch, where a ditch has been cut through one of these outcrops, the following forms were obtained from the debris—an assemblage which suggests that the various sub-zones of the Lower Birkhill group are here represented:

Diplograptus acuminatus (Nich.)
Dimorphograptus Swanstoni (Lapw.)
Diplograptus vesiculosus (Nich.)
Climacograptus normalis (Lapw.)
,, *rectangularis* (M'Coy.)
,, nov. sp.
Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *attenuatus* (Hopk.)
,, *leptotheca* (Lapw.)
Dawsonia campanulata (Nich.)

One feature which characterises the system of folding in the area just described between Garheugh and Low Glenling is worthy of note, viz.: that the sharpest folds, revealing the lowest strata, occur along the southern margin of the area, even though these folds do not run along the same axial line. They are arranged in *echelon*, the long axis of each successive deep fold being a little to the south of the preceding one as we pass towards the north-east.

Crows Burn, Ballaird.—Owing to the pitch of the folds the Moffat Shales bury themselves underneath overlying sediments to the east of the area just described. For a distance of nearly two miles to the E.N.E., only greywackes are met with, save at one locality, where a small patch of black shales is visible near the "White Dyke Spa"—a chalybeate spring, rather more than half a mile north by east of White Dyke Farm. The black shales reappear, however, to the north, near Ballaird, about half a mile to the west of Ballaird Farmhouse, where they occupy a considerable breadth of ground, along the line of the Crows Burn to the east of Crows Moor. This outcrop of Moffat Shales in the Crows Burn is bounded on the west by a cliff-like feature named the Cat Craigs, which forms the east margin of the Crows Moor. That this feature is due to a fault may be surmised from the fact that the black shales strike persistently at the greywackes of the escarpment.

This area, about a mile long and about 200 yards broad, stretches from the feature just mentioned to the road a little to the north-east of Ballaird Farmhouse. The most conspicuous beds in it are Barren Mudstones, but the Lower Hartfell black shales are also exposed, sometimes in the knolls, but chiefly in ditch-like cuttings in the course of the Crows Burn, about 800 yards W.N.W. of Ballaird Farm, where they have yielded *Diplograptus foliaceus*, *Climacograptus caudatus*, *Glossograptus Hincksi*. From another exposure, a little further down stream, *Diplograptus foliaceus* and *Climacograptus tubuliferus* were collected. In a field about 400 yards north of Ballaird, black shales occur next greywackes, from which *Monograptus leptotheca* was obtained, proving that part of the Birkhill Shales are here represented. In a quarry in a field close to the road, about 400 yards north-east of Ballaird, the Barren Mudstones occur with a mass of Hartfell black shales, the latter being much cleaved and shattered, and enclosing imperfect

specimens of *Diplograptus foliaceus* and *Climacograptus bicornis*. To the east of these outcrops, the black shales do not reappear throughout the area lying to the west of the estuary of the Cree.

Eldrig Loch.—About two miles to the south of the bands at Low Glenling, the Moffat series reappears at Loch-head, by the roadside east of Eldrig Loch, in Mochrum Parish, and again about a mile to the W.S.W., in a quarry, where the black shales form the back of an anticline. From the latter locality, fragments of *Monograpti* have been obtained, and from the former some Birkhill forms have been collected.

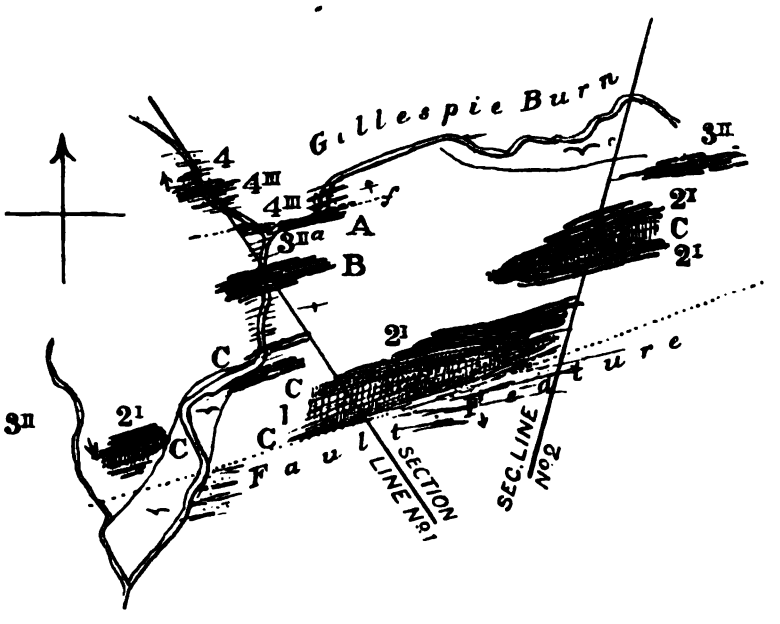


FIG. 37.—Plan of Gillespie Burn, Culroy, Glenluce Parish, Wigtownshire.

1. Mudstones (Arenig). C. Radiolarian chert. 2I. Glenkiln Shales. 3II. Lower Hartfell Shales. 3IIa. *Linearis*-zone. 3II'. Barren Mudstones. 4III. Lower Birkhill Shales. 4. Greywacke and shale (Llandovery). f. Fault. ~ Recent alluvium.

Culroy.—About two and a half miles to the north of the band at Garheugh the black shale series reappears near Culroy to the west of Castle Loch, Glenluce Parish. This band has been traced for 2½ miles, the best sections being visible in the Gillespie Burn (Fig. 37). At a point about 400 yards east of Culroy Farmhouse, this stream changes its course at a right angle and plunges into a rocky gorge, where the burn flows along a nearly vertical outcrop of Hartfell black shales. The following fossils were here gathered: *Diplograptus quadrimucronatus, D. foliaceus, Climacograptus caudatus, Cryptograptus tricornis, Climacograptus bicornis, Dicranograptus ramosus, Dicellograptus, Retiolites, Corynoides calycularis.*

On the north side of this exposure of the Hartfell Shales a small development of Barren Mudstones is succeeded by a thin band of blue-black shales, containing *Climacograptus*

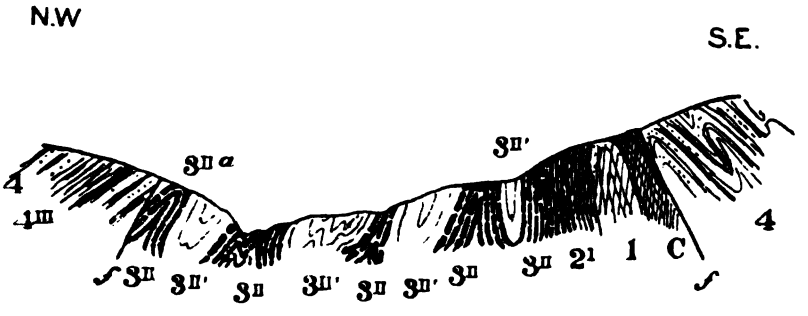


FIG. 38.—Section across Gillespie Burn (No. 1 in Fig. 37).

normalis, *Diplograptus*, and *siculæ* of graptolites, belonging to the Birkhill group. These strata are followed by greywackes and shales, with a thin black shale containing fragments of graptolites.

On the south side of the main exposure of Hartfell Shales the stream flows across Barren Mudstones. The Hartfell black shales reappear at two localities—one 50 yards (Locality B in ground-plan, Fig. 37), the other about 100 yards down stream (Locality C) from the main Hartfell outcrop (Fig. 38). The fossils from Locality B include *Diplograptus foliaceus*, *Climacograptus bicornis*, and *Dicranograptus*; those from Locality C, at the bend on left bank, comprise *Diplograptus foliaceus*, *Climacograptus bicornis*, *Corynoides calycularis*, and *Dicellograptus*. Some of the seams are crowded with specimens of *Diplograptus foliaceus*.

Descending the burn, the observer notes the radiolarian cherts and black shales on the right bank a few yards back from the stream. North-east of the stream, the red mudstones and black shales are visible in the cultivated fields, and are traceable for a distance of 700 yards from the burn section. To the north of the arch of red mudstones, the cherts appear on another fold, probably on the line of strike of the band B in the Gillespie Burn (see Figs. 37 and 39). This zone of cherts is also associated with black shales. Both these anticlinal folds are apparently truncated by a fault running in a north-east direction. Still further to the north, a third fold reveals the Hartfell black shales containing the following forms: *Diplograptus foliaceus*, *Climacograptus bicornis*, *Dicellograptus*, *Dicranograptus ramosus*.

Proceeding to the north-east, we find that the fault already described truncates these three folds in succession. At a distance of three-quarters of a mile north-east of Gillespie Burn, the Hartfell Shales on the northmost anticline are seen crossing the road leading to Barhaskine; a little further north, on the same road, dark shales in greywackes yielded the following forms: *Diplograptus acuminatus*, *D. tamariscus*, *Monograptus*

tenuis, *M. attenuatus*, *M. gregarius*, *Climacograptus normalis*. A little further to the north-east, on the footpath, in blue-black shales in greywackes, the fossils obtained were *Monograptus gregarius* and *Climacograptus normalis*. Here, then, it is clear that the representatives of the Birkhill Shales are enclosed in other sediments. A little over a mile and a half east-north-east of Gillespie Burn, the Birkhill Shales appear in a little quarry,

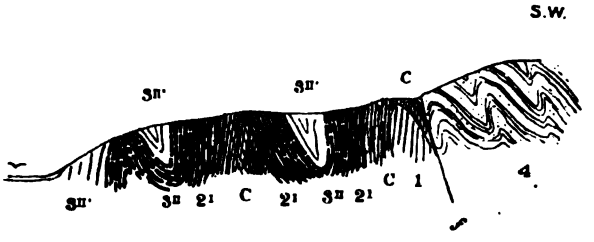


FIG. 39.—Section across Gillespie Burn (No. 2 in Fig. 37).

beside a footpath about 100 yards W.S.W. of a small loch in peat. Here in a blue-black platy iron-stained shale, fine specimens of *Diplograptus acuminatus* have been got, together with specimens of *Climacograptus normalis* and *Monograptus attenuatus*. The fault just mentioned gives rise to a prominent feature traceable eastwards to the little loch in the peat, and even beyond that point. At a point in the high road, about 300 yards N.N.W. from that loch, two folds of black shales appear, of which the most northerly yielded *Diplograptus acuminatus* and *Climacograptus normalis*.

In a little tributary of the Gillespie Burn east of Culroy, on the right bank, dark seams in blue shales embedded in greywackes contain *Diplograptus vesiculosus*, *Monograptus attenuatus*, &c. To the west of Gillespie Burn fragments of black shales may be seen in the fields, and even knolls of black shales and Barren Mudstones occur. But the folds of these strata appear to be gradually becoming narrower. In a burn, due west of Culroy Farmhouse, where a by-road or footpath crosses the burn, fragments of *Monograptus* were found in blue-black shales similar to those near Culroy. Again, by the roadside near Machermore, at a point about half a mile south-east of Whitefield Loch, fragments of indeterminable graptolites were obtained from similar beds.

The evidence given in the foregoing paragraphs indicates that in the Culroy band of Moffat Shales the representatives of the Birkhill division have to a large extent disappeared, and that the graptolites of the *D. acuminatus* zone occur in dark seams, interleaved in coarser sediments. This change becomes still more apparent as we approach the northern margin of the Llandovery and Tarannon area near Glenluce. A section exhibiting these features stretches along the east shore of Luce Bay, about a mile south of Glenluce, between the Fish-house and the Crow's Nest. Beginning near the Fish-house and advancing southwards, the

observer finds rusty mudstones resembling the Barren Mudstones, and calcareous bands with beds of greywacke, several feet in thickness. These are followed by greywackes and blue micaceous shales and mudstones, with dark bands and streaks sometimes calcareous. All the beds are nearly vertical or dip at high angles to the south. At a point about 200 yards south of the Fish-house two thin dark seams, ten yards distant from each other, yield graptolites sparingly. The more northerly layer encloses fine specimens of *Climacograptus normalis*, together with *Diplograptus acuminatus*, *Climacograptus* sp., and the *siculæ* and the young stages of a *Dimorphograptus*. The southerly one yields *siculæ* of graptolites and the same attenuated form of *Climacograptus*. These are followed by massive grey greywackes with thin bands of blue shales.

About 250 yards south of the foregoing fossiliferous localities certain thin bands in the greywackes yielded *Climacograptus* abundantly. About half a mile south of the Fish-house, beyond a series of massive greywackes with thin shales, dipping sometimes to the north and sometimes to the south, fossiliferous shales occur on the shore which closely resemble the *D. acuminatus* band already described near the Fish-house. Similar graptolites are obtained in great abundance in certain layers. These strata are followed southwards by mudstones, resembling lithologically the Barren Mudstones, and dip to the N.N.W. at high angles. About 100 yards south of the latter exposure, after traversing massive greywackes, we come again upon the blue shales with Lower Birkhill graptolites, which are followed southwards to the Crow's Nest by greywackes, grits, and thin shaly partings. About nine miles to the E.N.E. of the section here referred to, in the Tarf Water at Waulk Mill, about one quarter of a mile south of Kirkcowan, *Climacograptus normalis* is found in a thick dark seam in greywackes, thus confirming the disappearance of the Moffat type of the Birkhill Shales towards the northern margin of the Llandovery and Tarannon area.

In the long narrow tongue of land which stretches south from the sands of Luce Bay to the Mull of Galloway, various folds of the Moffat series appear in the midst of the overlying Llandovery strata. (Sheets 1 and 3 of Survey Map.)

Clanyard Bay, West Coast of Rhinns of Galloway. —Important sections of the Moffat Shales, ranging from the Barren Mudstones to the *M. spinigerus* zone of the Birkhill division, are laid open in this bay, which is about a quarter of a mile wide, measured from north to south. The exposures are confined to the north and south limits of the bay, the central portion being covered with sand and gravel or other marine alluvial deposits (Fig. 40).

Beginning with the section at the north end of the bay, the observer finds, as he proceeds northwards, that an excellent exposure of Barren Mudstones occupies the shore for a distance of 20 yards across the strike. These are the first rocks met with, and are apparently the lowest visible beds in this section. They consist of red, green, and grey mudstones with nodules of manganese or pisolitic ironstone, which lie along the bedding

planes, and measure from one to three, and in some instances six, inches across. The variation in colour of the mudstones from red to green and grey is purely local, and is not confined to separate bands. The strike of the beds is a few degrees to the north of east, the dip being sometimes to the north and sometimes to the south.

At their northern limit alternations of dark and green mudstones may be observed. The junction line between the top of the Barren Mudstones and the overlying Birkhill Shales is traceable along a ridge of rock through the gravel of the beach. About a foot below the base of the Birkhill Shales a seam of dark or black shales about half an inch thick furnishes good specimens of *Diplograptus truncatus* and *Dicellograptus anceps*. In the band of black shales in contact with the Barren Mudstones specimens of *Monograptus tenuis* and *M. attenuatus* were obtained. This zone is succeeded by black shales containing the following forms:

Diplograptus acuminatus (Nich.)
Dimorphograptus elongatus (Lapw.)
Diplograptus vesiculosus (Nich.)
Monograptus tenuis (Portl.)
Monograptus attenuatus (Hopk.)
,, *gregarius* (Lapw.)
Climacograptus normalis (Lapw.)
,, nov. sp.

To the north of these shales the Barren Mudstones reappear with a north-west dip. They here show a blue colour in fresh fracture, but weather brown or yellow. They are pierced on the north side by an intrusive dyke 29 feet broad. This dyke is succeeded by a mass of the Lower Birkhill Shales, visible at low tide. A few feet from the junction with the igneous rock the following forms were obtained from these shales:

Diplograptus vesiculosus (Nich.) in abundance and in excellent preservation.
Monograptus triangulatus (Hark.)
Monograptus tenuis (Portl.)
Diplograptus confertus (Nich.)
,, *tamariscus* (Nich.)

Measured from the north edge of the dyke there are 26 feet of black shales. Northwards a change takes place in the character of the sediments, for the succeeding 16 feet of strata consist of alternations of blue and black shales and clays, with nodules of ironstone and limestone. From the following assemblage of graptolites obtained from them, there can be little doubt that these strata represent the *M. gregarius zone.*

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *attenuatus* (Hopk.)
,, *leptotheca* (Lapw.)
Diplograptus tamariscus (Nich.)
Climacograptus normalis (Lapw.)
Monograptus cyphus (Lapw.)
,, *triangulatus* (Hark.)
Petalograptus palmæus (Barr.)
Rastrites peregrinus (Barr.)
Dimorphograptus Swanstoni (Lapw.)
Diplograptus confertus (Nich.)

A fault occurs along the northern margin of the *M. gregarius* zone.

To the north of the outcrop just described, a succession of blue-black shales and clays represents a portion of the Upper Birkhill

division. The *Diplograptus cometa* zone has not been noted, but a rich assemblage of forms occurs here in the *M. spinigerus* zone, those obtained being in excellent preservation:

Monograptus spinigerus (Nich.) in great abundance.	*Monograptus Hisingeri* (Carr.)
,, *spiralis* (Geinitz.)	*Rastrites maximus* (Carr.)
,, *attenuatus* (Hopk.)	,, *distans* (Lapw.)
,, *leptotheca* (Lapw.)	*Petalograptus folium* (His.)

The distance of the *M. spinigerus* zone from the fault is 10 feet, so that the dislocation is evidently of no great magnitude. To the north of this zone two dykes make their appearance. East of the northmost dyke jointed greywackes and shales occur, with a thin dark seam about a quarter of an inch thick, yielding fragments of graptolites.

At the south side of Clanyard Bay (Fig. 40) the black shales of the *Diplograptus vesiculosus* zone are seen at low tide dipping at high angles to the north-west. Specimens of this zonal graptolite have been collected here, together with *Climacograptus normalis*. These strata are underlain by a fine display of the Barren Mudstones, which occupy the beach for a distance of 41 feet. At a distance of 29 feet from the northern limit of the mudstones, a narrow band of black shales appears, probably an infold of the *D. vesiculosus* zone.

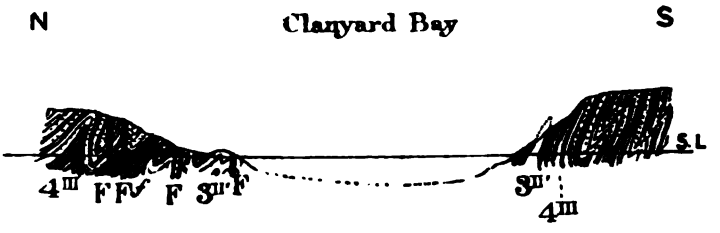


FIG. 40.—Section in Clanyard Bay, near Mull of Galloway.

3II'. Barren Mudstones. 4III. Lower Birkhill Shales. F. Felsite dykes. f. Fault. S.L. Sea level.

To the south of this compound arch of Barren Mudstones the shales of the *D. vesiculosus* zone succeed, followed by the black shales and clays of the *M. gregarius* zone, which in turn give place to blue-black shales, mudstones, and clays of the Upper Birkhill division, that graduate outwards into greywackes and shales. The general dip of the strata is to the north-west, so that the Moffat beds here form an isoclinal fold inclined to the N.N.W.

Drumbreddan Bay.—Proceeding northwards across the strike of the beds, we meet with the next exposures of the Moffat series in Drumbreddan Bay at the southern limit of Sheet 4 of the Geological Survey Map. This bay, which is about 300 yards wide, has a promontory of rock in the centre, dividing it into two

portions. The section which it affords is not continuous, for a large part of the beach is occupied with sand.

The ridge of rock that runs seawards in the centre of the bay is bounded to the north and south by a broad expanse of sand. On the south side of the rocky promontory at low tide a small arch of black shales occurs in a series of blue-black shales, with seams of clay, peering through the sand. From the black shales *Monograptus gregarius*, *M. triangulatus*, *Rastrites peregrinus*, *Climacograptus normalis*, and *Diplograptus* have been collected.

These strata are succeeded on the north side by grey clayey shales, dipping south at about 80°, with dark seams in thin leaves, from which the following forms were obtained: *Rastrites peregrinus*, *Monograptus tenuis*, *M. attenuatus*, *M. Hisingeri*, *Climacograptus*, and *Diplograptus*. They are followed northwards by grey shales, which enclose grey limestone nodules varying in size from a few inches to a foot across, and alternate with bands of flaggy greywackes that become thicker and more gritty as they are traced outwards from the Birkhill Shales. The section is interrupted by small faults.

South of the promontory an expanse of sand stretches for a distance of 80 yards. At the southern limit of the bay grey shales with dark seams occur, containing limestone nodules varying in size from a few inches to a foot or two across. These shales are interleaved with greywacke bands, the series graduating southwards into massive grits and shales. The grits enclose limestone nodules which weather out. The beds dip to the S.S.E. at angles of about 80°.

Proceeding now to the section north of the central promontory, where alternations of grits and shales form the last visible rock-exposures, the observer, after crossing a belt of 50 yards of gravel on the beach, finds another fold of the Moffat Shales at the north limit of the bay. Here, at low tide, at the base of the rocky cliff, black shales in grey clayey bands have yielded the following forms belonging to the *M. gregarius* zone:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
,, *leptotheca* (Lapw.)
,, *fimbriatus* (Nich.)
,, *triangulatus* (Hark.)
Rastrites peregrinus (Barr.)
Petalograptus palmæus (Barr.)
Climacograptus normalis (Lapw.)
,, *innotatus* (Nich.)
Dawsonia campanulata (Nich.)
Siculæ of graptolites.

These beds are succeeded at the base of the cliff by grey shales with dark films, like those on the south side of the central promontory, and then by sandy greywackes and shales.

Grennan Bay.—Round the headland of Grennan Point, brown-crusted grits, greywackes, and shales occupy the shore section as far as Grennan Bay, where a fine section of Birkhill Shales is exposed. At the south limit of the bay massive grits and shales dip south-east, the beds immediately in contact with them consisting of black shales with clayey seams. These black shales

yield graptolites in excellent preservation, belonging apparently to the *M. gregarius* zone:

Monograptus gregarius (Lapw.)	*Monograptus lobiferus* (M'Coy.)
,, *tenuis* (Portl.)	*Rastrites peregrinus* (Barr.)
,, *attenuatus* (Hopk.)	*Climacograptus normalis* (Lapw.)
,, *leptotheca* (Lapw.)	*Dawsonia campanulata* (Nich.)
,, *triangulatus* (Hark.)	

These strata contain limestone nodules from three inches to a foot across, and are traversed by a fault with a downthrow to the south. The black shales with limestone nodules yield *Diplograptus confertus* and a form like *Monograptus runcinatus*.

Further north, black shales of the *Diplograptus vesiculosus* zone contains *D. vesiculosus*, *Monograptus gregarius*, *M. attenuatus*, *M. tenuis*, *Climacograptus normalis*, *Dimorphograptus elongatus*, and *Diplograptus tamariscus*.

A constant repetition of the Lower Birkhill black shales, chiefly of the *D. vesiculosus* zone, may be traced northwards till an arch of Barren Mudstones is reached with flinty bands from seven to eight yards broad. On the north side of this arch there is a seam of black shale about one inch thick, followed by the Birkhill black shales. From the flaggy black shales the following forms were collected: *Climacograptus normalis*, *Monograptus tenuis*, and *Diplograptus tamariscus*. The next strata are black shales alternating with grey clays, succeeded by greywackes and shales. There seems, however, to be a line of fault at the north edge of the black shale series. This fine exposure of the Birkhill Shales occupies the coast line for a distance of about 70 yards.

Section near Float Bay.—About $2\frac{1}{2}$ miles to the north of the Grennan Bay band of black shales, another exposure of some members of the Birkhill division may be seen about a quarter of a mile to the north of Float Bay. Grey-blue shales with dark micaceous sandy seams occur on the north side of the bay, succeeded northwards by greywackes, grits, and shales. In the Dove Cave Bay, representatives of the *M. gregarius* zone are met with, as shown on the accompanying ground-plan (Fig. 41).

At A, on the cliff section, a zone of dark sandy shales contains *Monograptus tenuis*, *M. attenuatus*, *Diplograptus tamariscus*, *Climacograptus normalis*, and *siculæ* of graptolites. These beds seem to be thrown by a fault to the south side of the bay, for at B they have yielded *Monograptus gregarius*, *M. tenuis*, *M. attenuatus*, *Climacograptus normalis*. They contain limestone nodules from a few inches to a foot thick. In the centre of the shales at B a synclinal fold of grit may be observed to be marked with holes formed by the weathering out of calcareous nodules. Another exposure of shales with limestone nodules, probably on the same horizon, is seen on the shore a short distance to the north (White Laird's Loup, &c.).

Slunkrainy.—In the bay about 300 yards south of Slunkrainy, fossiliferous beds appear, which probably occupy the horizon

of the *M. gregarius* zone. They consist of blue shales with black strains, dark sandy shales with limestone nodules and interleaved with greywackes. The sandy shales have yielded *Climacograptus, Monograptus*, and *Dawsonia campanulata.*

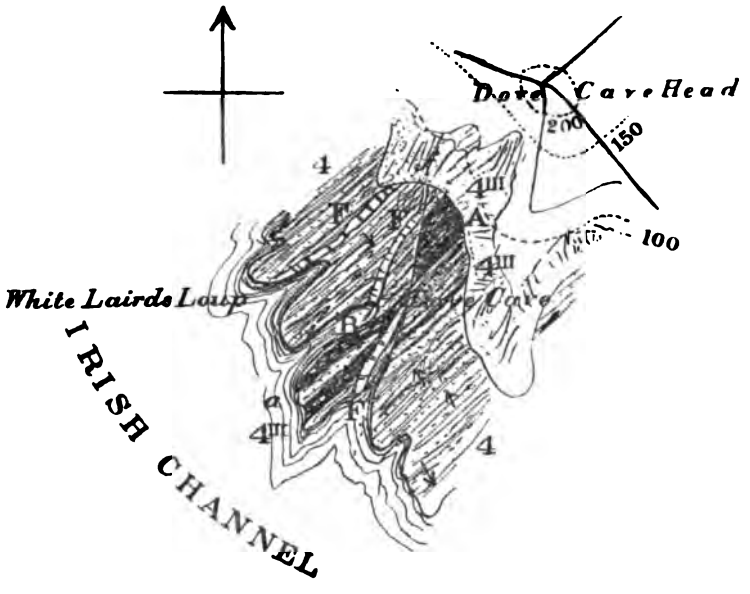


FIG. 41.—Plan of Shore at Dove Cave, Float Bay, West Coast of Rhinns of Galloway.

4III. Lower Birkhill Shales. 4. Greywacke and shale (Llandovery). a. Grit with limestone nodules. F. Felsite dykes. f. Fault.

Immediately to the north of Slunkrainy Point a good development of blue-black shales with limestone nodules may be seen. In a cave at this part of the coast a black shale forms the roof, from which were obtained specimens of *Climacograptus normalis, Monograptus*, and *Diplograptus tamariscus.* To the north, these fossiliferous zones are succeeded by a great development of grey shales and mudstones. The general dip of the strata is to the S.S.E., but it is certain that these shales with greywacke bands, though they extend along the coast line for some distance, are isoclinally folded.

At a point where a burn falls over the cliff into the sea, about a quarter of a mile south of Money Head, a band of black shales affords specimens of *Monograptus gregarius, M. tenuis, M. attenuatus, M. cyphus, M. leptotheca, Climacograptus normalis*, and *Dawsonia campanulata*, and probably represents the *M. gregarius* zone. It is the most northerly exposure of any recognisable fossiliferous zone representing the Birkhill Shales on the coast line between the Mull of Galloway and Portpatrick. Northwards this band is followed

by shales, greywackes, and grits, occupying the cliffs at Money Head and Scarty Head towards Cairnsgarroch Bay.

From the evidence supplied by the various exposures of the Moffat series on the shore between the Mull of Galloway and Money Head, we may deduce the following conclusions. The lowest visible beds are the Barren Mudstones, and the highest belong to the *M. spinigerus* zone of the Upper Birkhill division. The type of mudstones representing the Upper Hartfell group closely resembles that in the Moffat area; while the dark band near the top, with *Dicellograptus anceps* and *Diplograptus truncatus*, is still met with. The lower division of the Birkhill group, with its subordinate zones of *Diplograptus acuminatus*, *Diplograptus vesiculosus*, and *Monograptus gregarius*, is clearly recognisable, resembling closely the Moffat equivalents both in lithological characters and fossil contents. Further, it seems clear that in Clanyard Bay at least, and probably in the Grennan Bay arch, representatives of the Upper Birkhill division occur, including the *Cephalograptus cometa* and *M. spinigerus* zones. No trace, however, of the *M. spinigerus* zone has been recorded to the north of the Grennan Bay anticline in Sheet 3.

It is further observable that a marked change has supervened in the lithological characters of the strata between Clanyard Bay and Drumbreddan Bay to the north. The beds representing the *M. spinigerus* zone in Clanyard Bay, as already indicated, consist of blue-black shales, mudstones, and clays; while in Drumbreddan Bay this zone seems to be represented by grey shales with dark seams containing limestone nodules, followed immediately by flaggy greywackes and shales. In like manner the beds included under the *M. gregarius* zone consist in Clanyard Bay of black shales and clays; while several miles to the north, near Slunkrainy, the fossils of this zone appear in dark sandy shales interleaved in greywackes.

This gradual change in the character of the sedimentation of the Birkhill group, as we proceed northwards, is a feature which, as already indicated, is characteristic of the whole Silurian Tableland. It is one which has occasioned considerable difficulty in drawing a base line for the northern limit of the Llandovery and Tarannon Rocks.

CHAPTER X.

THE CENTRAL BELT—*continued.*

BLACK SHALE BANDS EAST OF PEEBLES AND SELKIRK.

Along the south-eastern margin of the Silurian Tableland, the Silurian rocks are buried under younger Palæozoic strata mainly of Upper Old Red Sandstone age. Indeed, the red sandstones and conglomerates of the latter formation stretch nearly across the tableland in Lauderdale, where, as already indicated, they fill an old Palæozoic valley. Further east, between Longformacus and Dunbar, a narrow belt of similar strata steals across the Silurian territory. Hence, the Tarannon Rocks between Lauderdale and St. Abbs Head form isolated areas separated from each other by Upper Old Red Sandstone.

Throughout the eastern portion of the Llandovery and Tarannon belt few axial folds expose representatives of the Moffat series. Those which do appear are not very satisfactory, as the order of succession and the relations of the strata are not very clearly defined. Nevertheless, there is important evidence to prove the intercalation of grits and other sediments in the Birkhill division of the Moffat series, near Innerleithen, in the Lugate Water, and in the Gala Water near Fountainhall.

There is one section, however, where some of the sub-divisions of the Moffat series still preserve the lithological types of the Moffat region, viz.: in the Rhymer's Glen, near Melrose.

Rhymer's Glen, Melrose.—The stream flowing through this romantic glen rises on the slopes of the Bowden Moor, about half a mile to the east of Coldshiels Loch, and runs in a northerly direction towards Huntlyburn House. In the lower part of its course it traverses volcanic tuff of later date than Silurian time (probably Carboniferous), of which a fine section is exposed in the channel of the stream, where it contains large bombs of trachyte. At its southern limit the tuff is mainly composed of angular blocks of greywacke. The junction of the two rocks is visible in the stream, a few yards below the point where it is joined by a small tributary on the west side. Here the greywackes and shales at the side of the footpath on the west side of the stream are truncated by the tuff. Some of the bands of shale are silky, resembling the grey shales containing *M. Sedgwicki* in the Upper Birkhill division of Moffat. Crossing the small tributary, and following the footpath southwards, we may still trace greywackes and shales on the west bank of the stream and at the side of the footpath. They are succeeded by grey mudstones,

which, weathering brown and resembling Barren Mudstones, are visible at the side of the footpath and dip S.S.E. It is probable that a fault intervenes between these mudstones and the greywackes and silky shales to the north.

The Barren Mudstones are followed on the south side by a fine exposure of black shales, vertical or nearly so, in the stream and at the side of the footpath. These shales yield graptolites of Hartfell age, as given in the following list:

Diplograptus foliaceus (Murch.)
,, *quadrimucronatus* (Hall.)
,, sp.
Dicranograptus sp.
Retiolites (Neurograptus) fibratus (Lapw.)
Climacograptus tubuliferus (Lapw.)
Climacograptus bicornis (Hall.)
Dicellograptus Forchhammeri (Gein.)
,, like *Morrisi* (Hopk.)
,, sp.
Leptograptus flaccidus (Hall.)
Siphonotreta micula (M'Coy.)

A fault truncates the southern margin of the black shales, and brings them in contact with Barren Mudstones, which dip south-east on the bank of the burn. Further up stream, the brown mudstones are succeeded by greywackes and shales, which are pierced by a trachyte dyke. At the waterfall, crushed black shales appear on the cliff on the east bank of the stream, which are so shattery that fossils are difficult to obtain in them. They are followed on the north side by grey greywackes and shales, and on the south side by greywackes, that form the waterfall and dip to the north at 75°. The latter are succeeded on the south side by greywackes and shales with silky seams, which have yielded to Professor Lapworth graptolites of Upper Birkhill age.

Further up stream, a fine trachyte dyke, which shows fluxion structure, runs along the west bank, and at the footbridge crosses the burn, where it is in contact with greywackes and shales.

Coldshiels Loch.—About three-quarters of a mile to the west of the section just described, the representatives of the Moffat series reappear at the S.E. margin of Coldshiels Loch, the intervening ground being covered with drift. When the loch is low and a flat selvage of its floor is exposed, grey shaly mudstones, red shales, and greywacke bands with dark seams are visible. These dark seams yield fossils in considerable abundance, belonging to the horizon of the Birkhill division and the lower portion of the Tarannon beds; as in the subjoined list:

Monograptus spinigerus (Nich.)
,, *spiralis* (Geinitz.)
,, *leptotheca* (Lapw.)
,, *cyphus* (Lapw.)
,, *Sedgwicki* (Portl.)
,, *Hisingeri* (Carr.)
,, *communis* (Lapw.)
,, *attenuatus* (Hopk.)
,, *triangulatus* (Hark.)
Monograptus lobiferus (M'Coy.)
,, *priodon* (Bron.)
,, *turriculatus* (Barr.)
Diplograptus tamariscus (Nich.)
,, *sinuatus* (Nich.)
,, sp.
Petalograptus palmæus (Barr.)
,, sp.
Climacograptus.

On a knoll about 100 yards south-east of the loch, in cultivated ground, debris of black shales occurs, in conjunction with greywackes. The horizon of these shales has not been proved.

Lindean Glen.—Westwards, about a mile from Coldshiels Loch, the Moffat Shales are again met with in a small burn about a third of a mile to the north of Lindean Farmhouse. At the head of the rocky gorge, greywackes and shales with white clays and dark seams are seen, followed further down, at the old "coal-pit," by black shales of the *D. vesiculosus* zone. These are succeeded by mudstones and crushed black shales, while at two localities contorted, much-jointed grey radiolarian cherts appear. Above the outcrop of the cherts, the black shales are truncated by a fault for a short distance along the north-east bank of the stream. The shales at this point are much crushed and veined with quartz, and graptolites are not easily obtained from them.

Further down, on the north bank, greywackes, clays, and dark seams, followed by grey and red mudstones, are succeeded, on the right bank, by black shales associated with grey shales and clays, which have afforded the following Birkhill fossils:

Rastrites maximus (Carr.)
,, *peregrinus* (Barr.)
Monograptus spinigerus (Nich.)
Monograptus lobiferus (M'Coy.)
,, *Hisingeri* (Carr.)
,, *attenuatus* (Hopk.)

The following species, ranging from the *Climacograptus Wilsoni* zone to the *Monograptus gregarius* zone, were collected many years ago from the beds in Lindean Glen by the Geological Survey:

Monograptus gregarius (Lapw.)
,, *tenuis* (Portl.)
Climacograptus normalis (Lapw.)
Diplograptus acuminatus (Nich.)
,, *foliaceus* (Murch.)
Lasiograptus sp.
Dicellograptus Forchhammeri (Gein.)
Buthograptus laxus (Hall.)
,, sp.
Siculæ of graptolites.

This locality is important from the occurrence of the rare form *Buthograptus*, the horizon of which has recently been proved in the Hartfell Scar section (Moffat), viz.: at the base of the *Climacograptus Wilsoni* zone. (See Page 137.)

From the evidence obtained along the line extending from the Rhymer's Glen to Lindean Glen, it is clear that the relations of the Moffat series have been much disturbed by faulting. Originally they must have been arranged as anticlinal arches. In the Rhymer's Glen, the lowest beds exposed are probably the Hartfell black shales, succeeded by the Barren Mudstones. The *D. vesiculosus* bands of the lower Birkhill horizon are not recognisable, but the representatives of part of the Upper Birkhill division occur.

River Tweed, Leaderfoot.—On the banks of the Tweed at Leaderfoot Bridge much shattered and crushed black shales appear, which have yielded *Diplograptus foliaceus*, *Climacograptus tubuliferus*, *Pleurograptus linearis*.

Pirn Quarry, Innerleithen.—In the exposures just referred to, some of the sub-divisions of the Moffat series still preserve the characteristics met with in the Central Moffat area; but in the valley of the Tweed, upwards to near Innerleithen,

evidence of the intercalation of members of the Birkhill group in coarser sediments has been obtained by Professor Lapworth, the late Mr. R. Mathieson, Innerleithen, and Mr. Wilson, Galashiels. For example, in the Pirn Quarry, by the roadside, about three-quarters of a mile east of Innerleithen, hard blue grits with bands of grey and dark shales, to all appearance regularly interbedded in them, include a band or lenticle of dark sandy shales lying on the face of the quarry, whence the following collection of graptolites was obtained by the late Mr. R. Mathieson, and named by Professor Lapworth:

Monograptus cyphus (Lapw.)
,, *argutus* (Lapw.)
,, *leptotheca* (Lapw.)
,, *crenularis* (Lapw.)
,, *tenuis* (Portl.)
Climacograptus normalis (Lapw.)
Dawsonia campanulata (Nich.)
Discinocaris browniana (Woodw.)
Orthoceras.

The following assemblage was collected by Mr. Wilson, Galashiels, from the same quarry:

Monograptus cyphus (Lapw.)
,, *gregarius* (Lapw.)
,, *argutus* (Lapw.)
Monograptus attenuatus (Hopk.)
,, *crenularis* (Lapw.)
Climacograptus normalis (Lapw.)

Woolandslee Burn (Leithen Water Basin).—Northwards from Innerleithen, the gradual disappearance of the representatives of the Birkhill Shales is still more apparent, for only fragments of undoubted *Monograptidæ* and other forms are obtainable in thin films intercalated in coarse sediments. About five miles up the Leithen Water, this stream receives the Woolandslee Burn, in which, about a mile up from the foot, brown, cleaved, micaceous shales appear, resembling the Lowther Shales, and having a general dip to N.N.W. At a point on the west bank of the stream opposite Woolandslee Tower, a form resembling *Diplograptus tamariscus* was found in a dark blue seam. Rather more than half a mile further up, and about 70 yards above the junction of a small burn on the east side of the valley, several graptolites were found in thin fissile shales with dark seams. The shales, which occur on the west bank, are shattery, iron-stained, and break into thin splintery fragments. From these beds two species of *Climacograptus*, *Monograptus tenuis*, *Dimorphograptus*, and *Diplograptus* were obtained. All these forms are here small. The peculiar shales that contain them closely resemble those at the roadside near Bower, on the Gala Water, to be described presently. They are here associated with blue flags and greywackes, either vertical or dipping down stream at angles from 70° to 80°. In this stream also, at the bend above Thorter Cleuch, and about a mile from the watershed, a section shows alternations of white clayey bands and grey mudstones or shales with black or dark seams, the latter yielding fragments of very minute graptolites (*Climacograptus* and *Diplograptus*). This locality is not far south of the boundary line of the Llandovery Rocks.

Ladyside Burn (Basin of the Heriot Water).—Still further to the north-east, graptolites belonging to the Lower Birkhill division have been obtained from thin seams in massive grits and greywackes in the Ladyside Burn, a tributary of the Heriot Water, eight miles north of Innerleithen. The Llandovery boundary line crosses this burn about 1100 yards south from its point of junction with the Heriot Water. North of this line a fine development may be seen of brown shales and mudstones, with limestone nodules; while to the south massive grits supervene with blue leaf-like seams, in which occur fragments of Birkhill graptolites. The best fossiliferous locality in this neighbourhood lies about a mile up stream from the junction with the Heriot Water. Here specimens of *Climacograptus normalis*, *Monograptus attenuatus*, *M. tenuis* (?) were obtained; also the proximal portions of graptolites, either *Monograptus* or *Dimorphograptus*.

Wolf Cleuch, Dewar Water.—Again in the small tributary of the Dewar Water named Wolf Cleuch, about seven miles north of Innerleithen, dark seams in the greywackes enclose fragments of *Climacograptus* like those intercalated in the Llandovery grits in Ladyside Burn. The Gala Water at Fountainhall, and the Lugate Water, with its tributaries, supply additional evidence of the intercalation of various sub-zones of the Birkhill Shales in grits, conglomerates, greywackes, and shales, as shown by Professor Lapworth. It would thus appear that various sediments of considerable thickness are interbedded with the Birkhill sub-divisions, ranging from the *D. acuminatus* zone to that of *Monograptus spinigerus*. Sections illustrating this feature occur near Fountainhall Station, and in tributaries of the Gala Water that drain the western side of the valley.

Quarry at Bower, near Fountainhall.—In this quarry, at the roadside, on the east bank of the Gala Water, about half a mile north of Fountainhall Station, a thin band of blue-black flaky shales is interleaved in greywackes and shales, yielding graptolites sparingly, and of no great variety, viz.: *Climacograptus normalis*, *Diplograptus*, and *siculæ* of graptolites. Not improbably this band may be on the horizon of the *D. acuminatus* zone. The strata exposed by the roadside south of the quarry consist of grits, greywackes, flags, and shales, dipping mainly to the north-west.

Still Burn.—In this tributary, which unites with the Gala Water about a quarter of a mile to the south of Fountainhall Station, some of the bands exposed have been correlated by Professor Lapworth with those of the *D. acuminatus* zone. Near the foot of the burn, at a point about 400 yards westwards from the Still Burn bridge, in a small tributary rivulet, grey, flaky, iron-stained shales occur, like those in the Bower Quarry. In the Still Burn, west from the wood, the strata resemble lithologically the Hawick Rocks. Further up the stream, and not far to the west of Howliston Farmhouse, blue-grey shales appear which might, on further examination, prove to be fossiliferous. They are exposed only at intervals, and consist for the most part of grey-blue

sandy shales with occasional flags, and as a rule are much crushed and shattered.

Sit Burn.—Crossing the watershed to the Sit Burn, which joins the Lugate Water about half a mile to the west of Overshiels, we find massive pebbly grits or conglomerates at a point about a mile up from the junction, not far below the spot where the Heathery Burn is crossed by a stone dyke. Above the junction of the two small streams, the Heathery and Fernie Burns, which unite to form the Sit Burn, an exposure of grey thick mudstone bands is succeeded soutwards by grits, the whole dipping up stream. Below the junction of the streams shales and sandy mudstones dip north-north-west at high angles, and are followed by grits. At a point half a mile up from the foot of the Sit Burn similar shales and mudstones appear. A little further down this stream, blue-grey sandy shales yield *Climacograptus normalis*. These strata are followed southwards by alternations of grits and shales, till, at and near the foot of the burn, greenish thick-bedded flaggy worm-piped shales are met with.

Lugate Water.—The geologist who ascends this stream above the foot of the Sit Burn comes upon the same worm-piped blue flaggy shales, together with grey shales and blue, almost black, mudstones. At one point about 300 yards west from the foot of the Sit Burn, blue, almost black, mudstones and shales, which yield *Climacograptus*, can be followed to the foot of the Ewes Water. About half a mile up the Lugate Water from that confluence an important section is to be seen in which certain bands furnish a suite of fossils characteristic of the *M. gregarius* zone. Here the stream divides near the west margin of Sheet 25 of the Survey Map. About 32 yards below the forkings, grey sandy platy shales occur dipping up stream (N.N.W.) about 70°. These contain dark or black seams alternating with grey shales, which have supplied the following forms:

Monograptus gregarius (Lapw.)	*Diplograptus tamariscus* (Nich.)
,, *attenuatus* (Hopk.)	*Petalograptus palmæus* (Barr.)
,, *triangulatus* (Hark.)	*Climacograptus normalis* (Lapw.)
,, *Sandersoni* (Lapw.)	*Rastrites peregrinus* (Barr.)
,, *concinnus* (Lapw.)	*Discinocaris browniana* (Woodw.)
,, *lobiferus* (M'Coy.)	*Peltocaris aptychoides* (Salt.)

These strata are followed northwards by pebbly grits and greywackes, visible a few yards above and below the fork. On the south side, the *M. gregarius* beds are likewise succeeded by grits, followed by sandy dark shales with calcareous ribs, and sandy mudstones with dark streaks yielding graptolites. Grits come next for a short distance, till at a point at the head of an alluvial plain, about 250 yards below the fork, grey-blue shales with dark streaks yielding *Rastrites peregrinus*, *Climacograptus normalis*, and *Diplograptus*, are met with. For a distance of 400 yards down stream no rocks are exposed, for the stream flows along an alluvial flat. At a point, however, 100 yards up from the junction with the Ewes Water, on the west bank, grey, sandy, shaly greywackes and shales

with dark strains, may be seen, from which the following forms were obtained, viz.: *Monograptus spinigerus, M. attenuatus, M. tenuis,* &c.

Ewes Water (Trously), tributary of the Lugate (Lugate-head).—This stream, above its junction with the Lugate, lays bare a good section of blue flaggy shales with grey sandy mudstones, and exposes also a band of fine conglomerate (Haggis Rock) a short distance below the shepherd's house of Trously. Further up the stream the strata consist of grits, flags, and shales, dipping to the N.N.W. and much shattered by faults. Below the point where several streams from the Deaf Heights unite, fault breccia is visible. Where the Ewes Water takes a bend to the south-west about half a mile to the south of Trously, blue sandy shales and flags with dark seams yielded the following forms:

Monograptus spinigerus (Nich.)
,, *attenuatus* (Hopk.)
,, *lobiferus* (M'Coy.)
,, *tenuis* (Portl.)
Monograptus (not determ.)
Rastrites sp.
Climacograptus normalis (Lapw.)

The scar that runs north and south from the Deaf Heights exposes grey sandy shales and mudstones and greywackes much weathered.

From the evidence now adduced, it seems clear that the *Monograptus gregarius* zone and the *Monograptus spinigerus* zone in the basins of the Lugate, and of the Gala near Fountain-hall, are intercalated in grits, conglomerates, and shales. These appear to be the normal outcrops of the respective zones along the northern margin of the Llandovery area. It is apparent, therefore, that a great change has here taken place in the lithological character of the Birkhill division, compared with the normal type of the Moffat region.

Earnscleugh Burn, 2½ miles N.N.E. of Lauder.—The representatives of the Moffat series reappear in an isoclinal fold in the Earnscleuch Burn, one of the tributaries of the Leader to the north-east of Lauder. In the lower two miles of its course this stream flows through Upper Old Red Conglomerate, excellent sections of which are visible on its north bank, west of Earnscleuch Farmhouse. About 200 yards north of that house, in an old channel of the burn, in two small exposures, the Lower Black Shales (Glenkiln-Hartfell) appear, much jointed, decomposed, breaking in small angular fragments, and including thin black flinty bands and decomposing yellow clays.

About 200 yards still further to the north-east a big scar rises on the north-west bank of the burn. At its western end greywackes and shales are truncated by a fault that brings them in contact with the grey cherts, black flints and shales; from which black shales the following fossils have been obtained:

Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
,, sp.
Dicellograptus moffatensis (Carr.)
,, sp.
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)
Corynoides curtus (Lapw.)
Cryptograptus tricornis (Carr.)

Some 200 yards still higher up, on the north bank, an exposure of dark grey sandy worm-piped shales has yielded *Monograptus lobiferus, M. exiguus, M. spinigerus, Monograptus* sp. From this point for a distance of half a mile, to within 200 yards from the mouth of Drakestruther Burn, there is a constant repetition of flaggy shales with calcareous ribs and grey flinty bands weathering with a cream colour. The last of these members has a certain resemblance to some of the flinty bands in the zone of radiolarian cherts, but there can be no doubt that they here occupy a position at or near the base of the Tarannon series. About 300 yards down stream from the mouth of the Drakestruther Burn, the shaly series now referred to yields *Myrianites.* At the northern edge of this series below Drakestruther Burn, massive grits alternate with shales, followed by a mass of grits that are pebbly in places.

For a distance of 200 yards above Drakestruther the Earnscleuch Burn flows along the strike of the beds of grit. Thereafter it bends at a right angle to the north, and traverses a peculiar series of dark shales with calcareous ribs and flinty bands. Still ascending the stream, we meet with a coarse pebbly grit, succeeded by shales. Next come alternations of grits and worm-tracked shales; some of the grits, as at Bermuda shepherd's house, being massive. About half a mile above that house, at a prominent bend of the burn, in a scar on the south bank, grey sandy worm-tracked shales and dark shales have furnished at the base of the cliff *Monograptus spinigerus*, and at the top *M. lobiferus* and *M. leptotheca.* Near this scar the stream takes a marked bend to the north, and from this point upwards the beds are chiefly composed of shales. About 150 yards up stream from the bend, shales on the south side of a massive grit yielded *Monograptus spinigerus*, while on the north side they furnished excellent examples of *M. lobiferus.* Northwards pebbly grits and brown sandy shales, at a spot 100 yards below the mouth of the Green Burn, supplied in great abundance from certain thin seams, *Monograptus spinigerus, M. leptotheca, M. lobiferus, M. attenuatus.*

For a short distance a band of grit is exposed, but owing to a slight bend in the strike the same shales with *M. spinigerus* appear in the stream, where they contain, in addition to the forms already mentioned, *Petalograptus palmæus.*

CHAPTER XI.

THE CENTRAL BELT—*continued.*

TARANNON ROCKS.

THE belt of territory, upwards of twenty-five miles in width, which stretches from the northern limit of the Llandovery strata on the slopes of the Moorfoot Hills and the Lowther range, to the boundary of the Wenlock and Ludlow Rocks along the southern margin of the Silurian Tableland, is occupied by strata mainly of Tarannon age. In the foregoing chapters we have described the various boat-shaped inliers of the Moffat series which, within this region, rise from underneath the younger Tarannon Rocks. We have indicated that throughout these numerous inliers the lowest zone of the Birkhill Shales, viz.: that of *Diplograptus acuminatus*, is regarded as the base of the Upper Silurian sediments of the Central Belt; for, as Professor Lapworth has shown, a great palæontological break intervenes between the Birkhill Shales and the underlying divisions of the Moffat series. The assemblage of graptolites found in the various sub-divisions of the Birkhill Shales proves that the beds containing them are of Llandovery age. In order, therefore, to complete the description of the rocks that enter into the structure of the Central Belt, we now propose to deal with those coarse-grained sediments which, though remarkably barren, nevertheless yield, at a few localities, fossils characteristic of the Tarannon Rocks of other regions.

Northern Base-line of Llandovery Rocks of the Central Belt.—In referring to the geological map of the Silurian Tableland, it will be seen that the Llandovery Rocks of the Central Belt are bounded by two great structural lines. The one on the south marks the upper limit of the Tarannon beds, where the latter pass conformably upwards into the Wenlock formation, while that on the north indicates the northern base-line of the Llandovery sediments, where they rise to the surface and are followed northwards by the representatives of the Bala, Arenig, and Llandeilo formations. The northern base-line extends along the tableland from the crest of the Lammermuirs in the far north-east to a point on the Wigtownshire coast about five miles south of Portpatrick. It is also observable that this boundary line along its outcrop follows a series of loop-like curves—a feature which might naturally be expected from the highly convoluted character of the rocks of the Silurian Tableland. For example, from the crest of the Lammermuirs the

boundary has been drawn across the head of Lauderdale by the southern declivity of the Moorfoot Hills, where the curvatures are very marked, to a point north of Peebles. Thence it sweeps up the valley of the Tweed, and by the Kingledores Burn to Elvanfoot, on the river Clyde, and from the latter point it has been traced along the southern slopes of the Lowther Hills, where the rapid flexures are again prominent, to Enterkine-foot, in Nithsdale. Westwards it follows a devious course by Dalry, in Glen Ken, and across the Wigtownshire moors to Glenluce, whence after passing underneath the sands of Luce Bay it crosses the south-western peninsula by Stoneykirk to a point south of Portayew Bay, on the shores of the Irish Channel.

It must be admitted that the tracing of this northern base-line has been a matter of considerable difficulty, and, in some parts, its delineation on the map cannot be regarded with complete satisfaction, for over much of the area we have failed to obtain conclusive palæontological evidence for fixing the precise position of the line. In the detailed descriptions of the various inliers of the Moffat series within the Central Belt, ample evidence has been given to show how the different sub-divisions of the Birkhill Shales gradually disappear or undergo important modifications, as they are followed north-westwards from the Moffat region. Where thin seams of dark shales, containing recognisable Lower Birkhill graptolites, are still traceable along the north-west margin of the Central Belt, the northern limit of the Llandovery Rocks may be fixed with approximate certainty. Where, on the other hand, only fragments of undoubted *Monograptidæ* and other forms are obtainable in thin films intercalated in coarse sediments, or where even these forms disappear, the boundary line laid down on the map can be regarded only as a provisional one which may be modified by future research. Referring for details to the evidence above adduced in proof of the gradual modification of the Birkhill Shales towards the north-west, we may here indicate generally the nature of the data for fixing the northern limit of the Llandovery Rocks.

Over the north-eastern portion of the Central Belt, in the basin of the Gala Water, and especially in the Lugate and Heriot Waters and their tributaries, representatives of the *Monograptus spinigerus*, *Monograptus gregarius*, and *Diplograptus acuminatus* zones are separated from each other by grits, conglomerates, greywackes, and shales along the northern margin of the Llandovery area. In some cases, as, for instance, in the Ladyside Burn in the basin of the Heriot Water, thin leaf-like seams interleaved in massive grits contain specimens of *Monograptus attenuatus*, *M. tenuis*, and *Climacograptus normalis*, which usually present themselves as dwarfed representatives of the forms so characteristic of the central Moffat region. The boundary line has here been drawn with approximate certainty along the northern margin of these sediments, which still yield recognisable Llandovery graptolites. South-westwards in the basin of the Leithen Water similar evidence is obtained, for there stunted

specimens of *Monograptus tenuis*, *Dimorphograptus*, *Diplograptus*, and *Climacograptus* may be gathered from dark seams in shales associated with greywackes, near the northern margin of the Central Belt.

Again, in the valley of the Tweed at Stobo, the boundary line has been drawn between the Stobo slates on the north, which are regarded as Caradoc, and certain massive grits to the south, believed to be of Llandovery age. Further up the river at Tweedsmuir, in certain dark blue shales associated with grits which are exposed at the foot of the Fruid Water, *Diplograptus vesiculosus*, *D. acuminatus*, *Climacograptus normalis*, and *siculæ* of graptolites have been obtained; while still further north the zonal Birkhill forms disappear, and attenuated representatives of *Diplograptus* and *Climacograptus* survive.

Between the Clyde and the Nith certain flaggy shales or slates with dark carbonaceous films, containing a large *Diplograptus*, an attenuated form of *Climacograptus* of *C. normalis* type, and *siculæ* of graptolites, which are exposed in various quarries and natural sections on both sides of the road leading from Elvanfoot to the Dalveen Pass, have been regarded as there forming the base of the Llandovery formation, since they are followed towards the north by the Lowther Shales (Caradoc).

Still further to the west, in that section of the tableland stretching from Nithsdale to the valley of the Ken, no characteristic Birkhill graptolite has been obtained from strata near the Llandovery boundary-line. The position of this line has there been fixed by the outcrop, towards the north, of grey mudstones and shales that represent the Barren Mudstones, and blue-black shales containing some of the characteristic forms of the *Pleurograptus linearis* zone. In the tract of metamorphosed rocks between New Galloway and Newton Stewart, with its two large granite masses, no palæontological evidence is available; but on the southern side of the Wigtownshire moors about Glenluce, similar phenomena to those already described are obtained. On the shore to the south of this town certain thin dark carbonaceous seams, embedded in greywackes and shales, yield dwarfed specimens of *Diplograptus acuminatus*, *Climacograptus normalis*, another stunted form of *Climacograptus* of common occurrence on this horizon, *siculæ* of graptolites, and specimens of the young stages of *Dimorphograptus*.

From these data it appears that along the northern limit of the Llandovery Rocks of the Central Belt, where the Moffat type of the Birkhill Shales has entirely disappeared, and where thin seams of carbonaceous shales, interleaved in greywackes and shales, contain a few dwarfed representatives of the prolific Birkhill fauna, the original physical conditions of deposit in Silurian time must have been unfavourable for the development of that group of organisms. The forms apparently indicate arrested stages of progress. If such be the true explanation, it may account for the difficulty in fixing the precise position of the northern base-line of the Llandovery Rocks. In the absence of palæontological evidence, this line has been drawn between the series

of massive grits, greywackes, and shales, which are the dominant feature of the Tarannon Rocks of the Central Belt, and the group of shales to the north (Lowther Snales, Stobo Slates, &c.), which are associated with the Hartfell black shales of the Northern Belt.

The broad extent of territory occupied by rocks, mainly of Tarannon age, in the Central Belt, is due solely to the extraordinary plication whereby the same strata are brought repeatedly to the surface. The numerous anticlines of the Moffat series afford conclusive proof of the reduplication of the strata by lateral compression, but even where the Moffat Shales do not appear at the surface, there can be little doubt that the overlying Tarannon Rocks have been similarly affected. For the observer has only to traverse any of the striking coast sections at either termination of the Central Belt to assure himself of this phenomenon. Since the time of Sir James Hall, the remarkable flexures of the strata between Cockburnspath and St. Abbs Head, in Berwickshire, have been classic features in Scottish geology, for there the system of normal and isoclinal folds may be studied in detail.

The phase of sedimentation represented by the Tarannon Rocks of the Central Belt differs widely from that of the underlying Birkhill Shales. Its dominant type is that of massive grits and greywackes (Queensberry Grits), which locally merge into conglomerates. This type is specially characteristic of the central and northern portions of the Central Belt. But towards the southern margin of the belt a remarkable change is observable, for there the highest Tarannon Rocks, which pass conformably upwards into the Wenlock formation, consist of brown-crusted flags, with grey, green, or red shales, and bands of brown or yellow greywacke from one to two feet thick (Hawick Rocks).

Though the Tarannon Rocks of the Central Belt are in general remarkably barren, there is one area in the tract, extending from Selkirk and Innerleithen to Melrose and Lauder, where fossils have been obtained from a large number of localities. The assemblage of organisms, as shown by Professor Lapworth, differs widely from that of the underlying Birkhill Shales, for it includes some graptolites which are survivors from these shales, some which pass up into the Wenlock strata, and others which are restricted to the Tarannon group. From the constant association of graptolite-bearing shales with grits and greywackes, and the rapid reduplication of the strata, it is difficult to establish a zonal sequence of the Tarannon graptolites. Further detailed investigation, however, may throw considerable light on this question.

North-Eastern District.

Beginning with that portion of the Central Belt which has proved the most fossiliferous, from Melrose and Selkirk in the south to Innerleithen and Lauder in the north, we find that the

Upper Birkhill Shales at Coldshiels Loch, south-west of Melrose, are immediately followed by mudstones, shales, and flagstones with *Monograptus turriculatus*, which is regarded as one of the zonal forms of the basal beds of Tarannon age. These strata pass upwards into brown flagstones and shales (Abbotsford flags), surmounted by massive grits and shales (Buckholm grits), which usually in the finer bands contain graptolites, with *Crossopodia*, *Myrianites*, and other tracks. Reference may first be made to the more important fossiliferous localities which have been detected in the region to the north of the arch of Moffat Shales in the Rhymer's Glen, and next to those on the south side of that anticline.

Packman's Burn.—In this stream, which joins the Leader Water about a mile to the north of Leaderfoot, a section of flagstones and shales with greywacke bands is exposed for about half a mile west from the railway bridge. The strata usually dip towards the north-west. At a point on the north bank, about 100 yards west from the railway bridge, the following fossils were obtained from a band of gritty greywacke, viz.: *Monograptus turriculatus*, *M. exiguus*, *Monograptus priodon*, *Dictyonema*, crustacean fragments, &c. About a quarter of a mile to the west of the same bridge certain beds yielded *Monograptus turriculatus*, *M. exiguus*, *M. priodon*, *M. galaensis*; while near the western termination of the rock-section thin grey shales furnished specimens of *Monograptus priodon*, *M. galaensis*, *M. vomerinus*, *Cyrtograptus* (?).

River Tweed near Melrose.—Along the strike of the strata seen in Packman's Burn certain sandy shales which appear in the Tweed at a cottage south-east of Pavilion and a mile and a quarter north-east of Melrose, have yielded specimens of *Monograptus exiguus*. Still further to the south-west, along the same line of strike, a similar assemblage of organisms may be observed in an old quarry, a few yards to the north of Cascade Farmhouse, on the north bank of the Tweed, and about a mile and a half west of Abbotsford. Here hard grey grit is associated with greenish grey shales, which contain *Monograptus turriculatus* in great abundance, together with *M. exiguus*, *M. galaensis*, &c.

Long Phillip Burn.—In this stream, which joins the River Ettrick opposite the town of Selkirk, about three and a half miles to the south-west of the last mentioned locality, certain blue-black shales at Corbie Burn have yielded *Monograptus exiguus*, *M. priodon*, &c., while at the foot of a small tributary rivulet the same forms occur with *M. crispus*.

Allan Water.—About a mile further north, across the strike of the strata, important fossiliferous bands are visible in this stream, which joins the Tweed about a mile and a half north-west of Melrose. Nearly opposite the Avenel Plantation (Geological Survey Map, Sheet 25) the following forms have been obtained from shales associated with greywackes in the Allan Water: *Monograptus exiguus*, *M. vomerinus*, *Diplograptus tamariscus*, &c. Again, about one-third of a mile further down, where a stone fence crosses the

water, a thin band of dark-blue shales, interleaved in greywackes and flags, has furnished the following assemblage of fossils:

Monograptus exiguus (Nich.)	*Monograptus attenuatus* (Hopk.)
,, *galaensis* (Lapw.)	,, *spiralis* (Geinitz.)
,, *priodon* (Bronn.)	

To the south-west of Avenel Plantation, on Westa Hill, at a point about a mile east of Galashiels, hard flaky grit and flaggy red shales, dipping to the north-west at angles from 65°–70°, have yielded specimens of *Monograptus turriculatus*, *M. crispus*, *Myrianites*, *Crossopodia*, &c.

Buckholm Hill.—The series of massive grits and greywackes which overlie the Abbotsford flags, greywackes, and shales are well seen on the Buckholm Hill, north of Galashiels, where they form rocky ridges, traceable south-westwards by the Meigle and Blakehope Hills to Cadonfoot, south of Clovenfords. In this region the shales associated with the massive grits yield a characteristic Tarannon fauna. A quarry at the road-side west of Buckholm Hill, about half a mile W.N.W. of Galashiels, has laid open an interesting section of massive grits and shales, the latter yielding specimens of *Monograptus exiguus*, *M. convolutus*, *M. proteus*, *Dexolites gracilis*, *Myrianites*, and branching tracks. In a quarry now abandoned at Buckholmside, Galashiels, and not far to the north of the locality just referred to, red and grey shale partings in massive greywackes have yielded *Monograptus crispus*, *Retiolites geinitzianus*, *Myrianites*, and other tracks. Nearly in the strike of the beds at Buckholmside, fossiliferous bands appear in the Ladhope Burn, at the old bridge about a mile above Buckholmside, where greyish blue shales have furnished the following, among other forms, viz.: *Monograptus exiguus*, *M. Sedgwicki*, *M. convolutus*, var. *communis*, *M. proteus*, *Petalograptus folium*, *Climacograptus normalis*.

The grits, flags, and shales of Buckholm, when followed south-westwards to Clovenfords and Cadonfoot, have been found to yield a characteristic Tarannon fauna.

Clovenfords and Cadonfoot.—Keeping to the road southwards from Clovenfords Station, in the direction of Cadonfoot, the observer comes upon a large quarry close to the railway viaduct at the bend near Cadonlee. Here the strata consist of alternations of flags, shales, and greywackes, which dip towards the N.N.W. at 75°. Some of the greywacke bands at the south side of the excavation are seven feet thick, while zones of shaly mudstones occur, one about two feet thick, in which the material breaks up into thin flaky particles. The fossiliferous bands vary in character; one type which decomposes into a light grey rock, stained with iron-pyrites, crumbles as a rule under a slight pressure, and is crowded with graptolites. Where fresh parts of this rock can be obtained, the fossils are well preserved. Another type consists of grey platy shales, weathering brown, in which the

graptolites, though not very abundant, are in excellent preservation. The fossils given in the subjoined list were here obtained:

Monograptus turriculatus (Barr.)	*Monograptus priodon* (Bronn.)
,, *exiguus* (Nich.)	abundant.
,, *crispus* (Lapw.)	,, *attenuatus* (Hopk.)
,, *galaensis* (Lapw.)	*Dictyonema* sp.

Southwards from this quarry, the greywackes and grits become more massive towards Cadonfoot, their general dip being to the N.N.W., at angles varying from 60° to 70°. At Cadonfoot, on the banks of the Tweed, in an old quarry now partly built over, a few yards to the south-east of the schoolhouse, red shales, interleaved in grey and blue shales, have been found to enclose *Crossopodia*, *Myrianites*, &c.

Cadonlee.—About half a mile to the north-west of Cadonfoot, and about a quarter of a mile north-west of Cadonlee Farmhouse, shales seen on the north side of the road leading to Galashiels dip to the north-west at angles varying from 45° to 50°. From certain thin dark seams, interleaved in these blue and grey fissile shales, the following graptolites were obtained:

Monograptus crispus (Lapw.)	*Diplograptus Hughesi* (Nich.)
,, *exiguus* (Nich.)	,, *tamariscus* (Nich.)
,, *galaensis* (Lapw.)	*Cyrtograptus* sp.
,, *Sedgwicki* (Portl.)	*Aptychopsis glabra* (Woodw.)
,, *priodon* (Bronn.)	*Dictyonema* sp.
,, *convolutus* (His.)	Plant remains.
,, *runcinatus* (Lapw.)	

Much in the same line of strike, and about half a mile north-east of Clovenfords, in a quarry on the south side of the road near Meigle Farmhouse, where massive greywackes and flags with red and grey shales have been exposed, the red shales contain remarkably fine examples of *Protovirgularia* and *Myrianites*, while the grey shales furnish *Monograptus priodon* and *Monograptus galaensis*.

Hillend.—About half a mile due north of Clovenfords, from a quarry at the wayside, near Hillend, a well marked suite of Tarannon fossils was obtained in blue shales and mudstones, with micaceous greywackes in bands and ribs. Some of the blue shales contain dark seams, which have yielded:

Monograptus turriculatus (Barr.)	*Retiolites* sp.
,, *exiguus* (Nich.)	*Diplograptus* sp.
,, *priodon* (Bronn.)	*Peltocaris aptychoides* (Salt.)
,, *communis* (Lapw.)	*Aptychopsis glabra* (Woodw.)
Petalograptus folium (His.)	*Ceratiocaris* sp.

Thornylee.—Still further towards the north-west, across the strike of folded strata of Tarannon age, an excellent section has been laid bare at Thornylee, in the valley of the Tweed, on the north bank of the river (Sheet 25 of Geological Survey Map). At the western limit of the rock-exposures, where greenish grey and red flaggy shales, alternating with bands of grit, dip to the north-

west at an angle of 70°, the shales are crowded with *Crossopodia*. South-eastwards, along the road towards the quarry, the beds roll over to the south-east, and in the quarry itself greenish grey and purple flaggy shales are seen to be charged with *Crossopodia* and *Myrianites*, together with *Monograptus exiguus*, *M. priodon*, *M. galaensis*, &c.

Basin of the Cadon Water.—As the observer continues north-westwards, across the strike of the Tarannon Rocks, he meets with these fossiliferous zones at intervals, with their characteristic organisms. For instance, on the east side of the valley, near Newhall, certain red and sandy shales, interleaved in thick-bedded greywackes and grits, which dip in a north-east direction at angles varying from 55° to 60°, have yielded *Myrianites*, *Crossopodia*, and other tracks. Again, on the east bank of the stream, near the farmhouse of Cadonhead, about four miles north-west of Clovenfords, certain greywacke bands, weathering spheroidally, and grey shales have furnished specimens of *Monograptus exiguus*, *M. spinigerus*, *Petalograptus folium*.

Similar evidence is found near the head-waters of the Cadon, immediately to the south of the moory watershed named the Deaf Heights, at the western margin of 25, one inch. Here the stream flows nearly east for about a mile, and at a point almost due south of the Deaf Heights, a scar on the north bank of the burn shows drab-coloured shales, with dark or blue-black seams, containing *Monograptus exiguus* in abundance, and *Monograptus pandus*. Not far to the west of this locality, where a crescent-shaped cliff bounds the northern margin of the alluvium, a fine exposure of grey and yellow shales has supplied graptolites in fine preservation, including specimens of *Monograptus turriculatus*, *M. exiguus*, *M. pandus*, *M. spiralis*, together with *Myrianites* and *Crossopodia*. Further west, near where the Cadon Burn enters Sheet 25 of the Map, the following forms have been obtained from grey sandy shales, viz.: *Monograptus exiguus*, *M. convolutus*, *M. communis*.

Innerleithen District.

On the other side of the watershed between the sources of the Cadon and certain tributaries of the Tweed, near Innerleithen, confirmatory evidence is obtained of the presence of Tarannon graptolites in strata which are evidently the south-west prolongations of those in the higher part of the Cadon Water. About two miles east of Innerleithen the Walker Burn, about a mile up from its junction with the Tweed, divides into two branches, that drain the slopes of the Glede Knowe (1915 feet) and the surrounding heights. About 200 yards up the east branch, flaggy dark blue shales appear, which contain thin leaf-like dark seams, yielding *Monograptus exiguus*, beautifully preserved in the solid form, *M. Sedgwicki*, *Rastrites maximus*, *Petalograptus folium*, and *Climacograptus normalis*. In the west branch similar evidence is obtained not far below the level of the 1250 feet contour line, where slaty

shales appear in the stream and dip to the north-west at 75°. About 50 yards above that level, in a fine exposure of platy and flaggy shales with dark seams, inclined in a similar direction, one of the carbonaceous layers contains *Monograptus turriculatus* in great abundance and in excellent preservation, together with other forms. Further up the burn other shales appear, in which one of the graptolites resembles *Monograptus spinigerus*. These strata continue in the section for some distance upwards. Near the source of the burn, dark shales with decomposing clays are the last visible strata in this tributary of Walker Burn.

Grieston Quarry.—The strata in this quarry have been familiar to geologists since Professor Nicol first recorded graptolites from them. They consist of blue and grey slaty shales, with occasional thin seams of limestone or calcareous ribs, from ¼ to ½ an inch thick, and are inclined to the north-west at high angles. The following fossils were obtained from this quarry by the Geological Survey: *Monograptus priodon, M. convolutus, M. vomerinus, M. Sedgwicki, Retiolites geinitzianus, Myrianites* sp. From the same locality have been recorded the following additional forms: by Professor Lapworth, *Monograptus colonus* and *Diplograptus*; by Mr. R. Mathieson, a *Discinocaris*; and by the Innerleithen Alpine Club, *Monograptus tenuis*.

Lauder District.

Turning now north-eastwards along the strike of the strata, from Innerleithen, across the Cadon and Gala Waters to the neighbourhood of Lauder, we find at various localities characteristic assemblages of graptolites of Tarannon age. To the south-west of the village of Lauder, red and purple flaggy shales and grits are visible in the Lauder Burn, and also in certain quarries, with a general dip to the south-east at high angles. In one of the quarries, about a mile south-west of Lauder, certain red shales contain *Monograptus priodon, M. Sedgwicki, M. leptotheca, M. convolutus, M. spiralis, Climacograptus*. Again, about two miles to the north-west of the village of Lauder, in the Harry Burn, nearly opposite Old Whiplaw, specimens of *Monograptus priodon, M. galaensis*, &c., have been obtained from shales.

Bruntaburn.—To the north-east of the Upper Old Red Sandstone of Lauderdale a triangular tract of strata mainly of Tarannon age has likewise yielded characteristic fossils. In the area between the arch of the Moffat series in Earnscleuch, and the margin of the Upper Old Red Sandstone at Spottiswoode, several exposures of fossiliferous bands furnish Tarannon graptolites. Near the mill at Bruntaburn, west of Spottiswoode, red flags, with a dip to the N.N.W., furnish specimens of *Protovirgularia dichotoma, Myrianites, Crossopodia*, and other tracks. This is one of the few localities in the Tarannon area of the Central Belt where *Protovirgularia* occurs in great abundance. Above Bruntaburn Wood thick-bedded shales have yielded *Crossopodia, Crosso-*

chorda, *Myrianites*, and other tracks. Again, in the higher part of this stream, where it receives the name of Pondreigh Burn, grey shales with grit bands appear close to the footpath leading to Flass, where they have furnished an interesting suite of fossils, viz.:

Monograptus exiguus (Nich.)	*Petalograptus ovatus* (Barr.)
,, *priodon* (Bronn.)	,, *palmæus* (Barr.)
Rastrites maximus (Carr.)	

Wedderlie Burn.—About three miles to the north-east of the exposures in Bruntaburn, fossiliferous bands reappear in the Wedderlie Burn, near Wedderburn Farmhouse, where some red and grey mudstones have furnished specimens of *Protovirgularia*, *Crossopodia*, *Myrianites*, &c., and sandy shales have yielded *Monograptus exiguus*, *M. convolutus*, *M. spiralis*, and *Retiolites*.

Blythe Burn.—Similar evidence is obtained in the Blythe Burn and its tributaries, for at the bend in the stream north from Heugh Farmhouse, reddish-green shales have yielded specimens of *Monograptus exiguus*, *M. priodon*, and tracks. Again, in the slate quarries on the east side of the burn, near the farmhouse of Blythe, the following forms have been obtained from blue shales: *Protovirgularia dichotoma*, *Crossopodia scotica*, *Myrianites*, and radiating worm-burrows. In a streamlet near the same locality examples of *Monograptus exiguus*, *M. priodon*, &c., were collected. Further up the Blythe Burn, at a sheep-fold about half a mile below Howebog, certain sandy shales have furnished specimens of *Protovirgularia*, *Myrianites*, &c., and near Broadshawrig, *Monograptus exiguus* and *M. galaensis*. At the last-named locality the Blythe Burn is joined by the Easter Burn, in which a fossiliferous conglomerate, about 150 yards up from the junction of the two streams, contains the following organisms in an imperfect state of preservation, viz.: *Orthis* or *Strophomena*, *Palæocyclus*, *Petraia bina*, coral, crinoid stem, *Ptilodictya*. A similar pebbly grit or fine conglomerate reappears in the Wheel Burn, south-west of Wheelburn Law.

Whelplaw Burn.—Near the northern margin of Sheet 25 of the Survey Map, and to the north of the anticline of the Moffat Shales in the Earnscleuch, Tarannon fossils are likewise found in the Whelplaw Burn—a tributary of the Leader Water—at a point about 400 yards up stream from Longcroft Farmhouse, where brown mudstones, weathering spheroidally, furnish specimens of *Monograptus crispus*, *M. exiguus*, *M. attenuatus*, and are associated with grey flaggy shales and greywackes.

District South of Melrose.

In the district south of Melrose, comparatively few fossiliferous localities have been met with in the Tarannon Rocks. On the banks of the wooded glen at Faldonsidemoor a good section may be seen of thin-bedded brown greywackes and flagstones, with grey and blue shales; the latter yielding *Monograptus vomerinus*, *M. priodon*, *M. galaensis*. In the Bowden Burn, which flows E.N.E. along the strike of the Silurian rocks and joins the Tweed near

Dryburgh, fossils have been found in the strata belonging to the typical Hawick Rocks. South of the village of Bowden, between Bowden Mill and Maxpoffle, grey-blue calmy shales and flagstones appear, followed further down stream by purple and grey shales with hard ribs or grey earthy decomposing greywacke. The former series, near Maxpoffle, has furnished a telson of *Eurypterus*, fragments of *Dictyocaris*, and crinoid stems.

In the neighbourhood of Selkirk, as for example on Selkirk Common, where the strata lie well to the north of the anticlines of the Moffat Shales at Melrose and Ettrickbridge-end, some of the beds consist of grits from 8 to 10 feet thick, which may possibly represent some of the thick bands of the Buckholm Grits. The strata, as seen in the quarry on Selkirk Common, are normally folded, while along the same line of strike to the south-west of Ettrickbridge-end, they are repeated by isoclinal folds which have a persistent dip to the north-west. Although no graptolites have been obtained from these rocks in the neighbourhood of Selkirk, some of the shales are crowded with *Crossopodia*, *Myrianites*, and other tracks so common at Thornylee and Grieston. Mr. Pringle of Selkirk has obtained specimens from a quarry at the roadside near Merrycourt Park, about a mile north of Greenhill, which show that the two sets of tracks figured by Salter in his Appendix to the memoir on the Geology of East Lothian (pp. 70, 71) must have been produced by the same animal.

District between Ashkirk and Hawick.

South of the district around Ettrickbridge-end and Selkirk, the most typical development of the so-called "Hawick Rocks" is to be seen. They consist of greenish-grey shales with thin bands of greywacke, which are singularly destitute of fossils. Innumerable exposures throughout the belt show that the rocks are intensely plicated; the axes of the folds being for the most part vertical.

Though no graptolites have as yet been collected from the strata in the neighbourhood of Hawick, yet *Protovirgularia*, *Crossopodia*, *Nemertites*, *Nereites*, and other tracks are abundant in some of the shales; all of which are to be found in Stirches Quarry near that town. From the same locality a specimen showing the body segments of a species of *Ceratiocaris* was obtained by Mr. Andrew Waugh, Hawick, and presented to the Geological Survey. For a distance of three miles to the north of Hawick this sub-division of the Tarannon Rocks preserves its normal characteristics. The strata show constant reduplication by folding, the axial planes of the folds being there generally inclined to the south-east.

Cockburnspath and St. Abbs District.

The coast line from Cockburnspath to St. Abbs Head, and thence to Burnmouth, north of Berwick, displays a magnifi-

cent section of rocks of Tarannon age, where both types of sedimentation are represented, first the massive grits and greywackes (Queensberry Grits) and the brown weathering flagstones, greywackes and calmy shales (Hawick Rocks). The various convolutions of the strata exposed in this remarkable section are described and illustrated by Sir A. Geikie in the Survey Memoir on the Geology of Eastern Berwickshire, from which the following extract is taken:—

"Standing on the western verge of the precipices of St. Abbs Head, the observer sees before him one of the wildest cliff-lines on the East of Scotland. The Silurian strata are there thrown into vast folds, which in oft-changing curves jut out, headland after headland, here worn into dim twilight creeks, there standing up as tangle-covered reefs and skerries, or grey sea-stacks, round which the gull and the auk and the solan goose are wheeling above, while the surge is ever breaking into foam below. His eye can trace the stratification of the cliffs as the sunlight falls on each successive promotory, now on an arch that has been half removed by the ocean, now on a trough that descends deep into the precipice, until these details are lost in the blue distance, as the coast-line bends away by the rocks of Fast Castle."

Along that part of the coast-line extending from Cockburnspath to St. Abbs Head, there are constant repetitions of massive greywackes, grits, flagstones, and shales (Queensberry Grits), while the peculiar lithological type representing the "Hawick Rocks" is found near Eyemouth. Near the Siccar Point, Sir A. Geikie, together with Ramsay and Salter, obtained a specimen of *Monograptus priodon* in the course of the survey of that district, which was figured by Salter in the Appendix to the Memoir on the Geology of East Lothian. In the course of the re-examination of this region by the Geological Survey, a characteristic suite of Tarannon graptolites was recently obtained from an old slate quarry about half a mile south-west of Siccar Point; possibly the same locality which long ago yielded *Monograptus priodon*. The excavation is situated about 250 yards to the north-east of the farmhouse of Old Cambus, in an old dry water-course. Here grey and red fissile shales and grey flaggy shales, weathering brown, dip in a S.S.E. direction at an angle of 30°, and contain fossils in considerable numbers in certain seams. The following list comprises the forms obtained by the Geological Survey:

Monograptus priodon (Bronn.)	*Monograptus crispus* (Lapw.)
,, *pandus* (Lapw.)	,, *Barrandei* (Tullb.)
,, *galaensis* (Lapw.)	,, *turriculatus* (Barr.)
,, *Hisingeri* (Carr.)	,, *leptotheca* (Lapw.)
,, *convolutus* (His.)	*Diplograptus sinuatus* (Nich.)
,, *exiguus* (Nich.)	

In addition to these graptolites the same strata yield *Crossopodia*, *Myrianites*, and other tracks.

Moffat District.

In the Moffat region, the Tarannon Rocks may be grouped as follows:—(1) Purple and grey flags and shales; (2) greywackes and shales with massive grits and bands of conglomerate (Queensberry Grits); (3) grey, green, and red shales with rusty brown flags and greywacke bands (Hawick Rocks, Ardwell Group). The lithological characters of these various groups closely resemble those already described as occurring in the north-east portion of the Central Belt.

The green and grey shales of the first sub-division are well seen at the waterfall in the lateral gorge at Dobb's Linn, where, with an inverted dip, they rise from underneath the *Rastrites maximus* zone of the Upper Birkhill beds. In many of the anticlines to the north of Dobb's Linn, where the Birkhill zones partly or wholly disappear, this zone of green, grey, or purple shales is conspicuous. It is not improbable that this group of shales may in part represent the Birkhill beds. To the north and east of Dobb's Linn the phase of sedimentation indicated by the Abbotsford flags intervenes between the Birkhill division and the massive grits, which are there represented by grey or purple shales and flags with thin greywacke bands.

Next in order come the massive grits, greywackes, and shales of the second sub-division, the bands of grit varying in thickness from two to twenty feet. The thin partings of shales in this arenaceous series in one or two instances yield fossils; as, for instance, on Hunterheck Hill, two miles north-east of Moffat, where *Dexolites gracilis*, *Crossopodia scotica*, and *Myrianites tenuis* have been obtained. Occasionally the pebbly grits merge into bands of coarse conglomerate. One of these in the neighbourhood of Moffat is locally known as the "Bannock Rock." The various outcrops, evidently repeated by folds, are indicated on the Map (Sheet 16) between Moffat and Hartfell. Again, towards the northern margin of the Llandovery area, a prominent band of conglomerate has been traced from the basin of the Clyde to the valley of the Tweed. One locality where it is typically developed is in the Pinstane Hill, about a mile and a half to the E.N.E of Little Clyde (Sheet 16). Here the rock possesses a greywacke matrix, in which are embedded rounded pebbles of quartz, red chert with radiolaria, Arenig volcanic rocks, with boulders of granite and quartzite from 8 to 10 inches in diameter. Some small pieces of mica-schist have also been observed. The fragments of quartzite and mica-schist resemble rocks of those types in the Eastern Highlands; there can be little doubt that they were derived from that region. Their occurrence, therefore, in the Llandovery conglomerate at Pinstane suggests that some at least of the crystalline schists of the Eastern Highlands had been elevated and denuded prior to Llandovery time. Towards the northern limit of the Llandovery area, the massive

grits seem to pass laterally into greywackes with zones of shale (Dalveen Group).

From certain microscopic sections of the Llandovery greywackes and grits from this region, examined by Mr. Teall, it appears that some of the bands contain quartz, orthoclase, microcline, plagioclase, mica, and fragments of various volcanic rocks belonging to the andesitic and felsitic groups. It is clear, therefore, that both volcanic and plutonic rocks have contributed to their formation. The fragments are angular or sub-angular. Well-rounded grains are rare. There is, further, a very great variability in the sizes of the constituent grains; indeed, the material does not appear to have been well sorted by aqueous action.

For a distance of nine miles to the north of Moffat the Tarannon Rocks (Queensberry Grits), as has been shown in the foregoing chapters, are constantly repeated by a series of inverted folds, the prevalent dip being towards the north-west. An interesting feature connected with this plication of the strata in the northern region is the development of slight schistosity in the grits, greywackes, and shales. This alteration is specially noticeable in a belt of ground, three miles in width, between Nether Howecleuch in the Eyan Water and the Little Clyde, excellent sections being visible in the railway cuttings. Under the microscope Mr. Teall has observed that "these schistose greywackes have a well-marked micro-flaser structure, and that the fine material of the matrix sweeps round the larger constituents in fluxion curves. These constituents occasionally give undulose extinction, indicative of strain, but they have not been much broken, and are as a rule sharply separated from the matrix. Peripheral granulation, so common in the gneissose grits of the Southern Highlands, is entirely absent." The shales are converted into slates approaching phyllites, "the main mass being a fine-grained aggregate very difficult to resolve under the microscope into distinct individuals. It consists apparently of quartz and sericite, with minute grains and crystals of rutile and a small quantity of brown or black granular matter, which gives a dirty aspect to the microscopic section. The sericite occurs in the form of very minute scales."

The normal type of the Queensberry Grits of the Central Moffat area extends as far south as Ettrick Pen. A line drawn north-east and south-west along the south side of the watershed on that hill roughly indicates the southern limit of this type of sediment, for to the south and east of that line the rocks lose their massive character. For some distance to the south of this line, the strata consist of flagstones shales, and greywackes, repeated by sharp isoclinal folds whose axial planes dip to the north-west at low angles. The greywackes are traversed by a series of joints coated with quartz and calcite, and break into sub-angular blocks or fragments. The shales are rudely cleaved, though the cleavage is by no means persistent.

Reference may now be made to certain shales yielding graptolites which occur in the Tima Water, Rankle Burn, and at Deloraine, in the basin of the Lower Ettrick. Some of these

bands yield *Monograptus exiguus*, and it is therefore probable that they belong to a higher horizon than the *Rastrites maximus* zone of the Birkhill Shales, and may be of Tarannon age.

Tima Water.—In the Lower Ettrick Valley the Tima Water, about a mile above its junction with the Ettrick, exposes thin black seams which dip steadily to the north-west at angles from 30° to 60°. At the northern margin of their outcrop a few graptolites have been obtained, where the shales are succeeded by alternations of black grits and shales with thin bands of black shale. The beds seen furthest up stream consist of grey and green mudstones. The strata in the Tima Water and on the Law Kneis Hill to the east are repeated by isoclinal folds and are accompanied by reversed faults.

Rough Sike, Gamescleuch.—Two thin bands of dark shale in this section yield imperfectly-preserved graptolites. In the Annelshope Burn, about 600 yards above Annelshope, similar seams contain *Monograptidæ*.

Rankle Burn and its Tributaries.—At the roadside at Cacrabank, on the Rankle Burn, a thin, dark, rusty band, interleaved in blue shales and flaggy greywackes, supplied *Monograptus exiguus*, *M. crispus*, and *M. priodon*, forms which are characteristic of the Tarannon shales north of Melrose. Near the head of the March Sike, joining the Rankle Burn from the east, grits of the Queensberry type come to the surface, stained red with hematite. For a distance of about 50 yards below this point red greywackes and shales, with silky bands yielding *Rastrites maximus* (Carr.) and other forms, dip towards the north-west at angles from 40° to 50°. They are succeeded by black grits, among which two thin seams of black shale yielding *Diplograpti* are associated with dark grey greywackes and shales, followed by a band of black shales from four to five inches thick yielding *Monograptus exiguus*.

Not far to the south, greywackes and shales are thrown into an isoclinal fold, and rise again with an apparent normal dip to the north-west. These strata rest on calcareous grits with galls of black shale, succeeded by rusty grits and greywackes underlain by decomposing rusty mudstones, which, by means of a reversed fault, are made to overlie thick-bedded greywackes. Below this point the stream cuts through boulder clay. But from the evidence now adduced it is probable that there is here the remnant of a fold, the southern limb of which has been removed by a reversed fault.

Again, on the right bank of the Deloraine Burn, about 350 yards below the shepherd's cottage, dark shales with *Rastrites maximus* dip to the north-west at 25°. Another anticline occurs on the left bank south of the cottage.

On the slope of Mossbrae Height, south of the river Ettrick, grey grits dip at from 15° to 30°. The north-east face of the hill presents an overhanging cliff, the upper portion of which is composed of grits, the lower of grey shales with dark bands yielding *Rastrites maximus*, *Monograptus crispus*, *M. Sedgwicki*. In the hollow that curves round the hill fragments of mudstones and black shales were observed.

To the south-east of the watershed of Ettrick Pen representatives of the "Hawick Rocks" occupy the valleys of the Teviot, the Borthwick Water, the Dryfe Water, and some of the tributaries near Eskdalemuir. They consist of rusty greywackes, pale argillaceous shales, and flagstones with zones of red shale. Like the prolongations of this series in the far north-east of the Central Belt, these beds are remarkably barren. Professor Harkness, however, obtained *Protovirgularia Harknessi* from a band in this series in the railway cutting near Lockerbie.

From the apparent order of superposition, as indicated by the inclination of the strata, one might infer that the "Hawick Rocks" are here arranged in the form of an anticline, the axis of which appears to run from Eskdalemuir by Lochmaben to Dumfries. This structure is, however, entirely deceptive. The strata, as a result of intense lateral compression, have been thrown into folds, of which the axial planes dip outwards from a central line; that is, towards north-west and south-east from a line running along Eskdalemuir.

District between the Nith and the Cree.

In the region between the Nith and the Cree, the Tarannon Rocks may be arranged in three divisions, similar to those already described, viz.: (1) Flags and shales with greywacke bands yielding forms characteristic of the *Monograptus turriculatus* zone, (2) massive (Queensberry) grits and greywackes, (3) Hawick Rocks or Ardwell Beds.

The members of the first two groups stretch from Castle-Douglas to Dalry and New Galloway, where they lie in synclinal folds, frequently inverted between the successive arches of the Birkhill Shales. On the south side of the Moffat black shale band, exposed in Trowdale Glen (p. 164), beds belonging to the *Monograptus turriculatus* zone make their appearance in a small quarry on the north side of Mountskip Plantation, and about 500 yards south of Trowdale Glen. A dark band, interleaved in shales and greywackes, has there yielded the following forms:

Monograptus turriculatus (Barr.)	*Monograptus attenuatus* (Hopk.)
,, *exiguus* (Nich.)	*Diplograptus palmæus* (Barr.)
,, *tenuis* (Portl.)	*Aptychopsis minor* (Barr.)

The Tarannon age of the flagstones and shales above the Birkhill division of the Moffat series is defined by the occurrence of *Monograptus exiguus* in a dark seam in green shales south-west of the Coal Heugh, on the south slope of the Culcaigrie Hill, and also near the Benjarg Wood, between Kirkcudbright and Gatehouse.

To the north of the Moffat Shales, at the village of Lawrieston, reddish grey flags and shales follow in regular sequence and dip underneath the coarse purple grits of the Livingstone and Dornell Hills. By means of folding, the grits are spread northwards to the slope of Ulloch Hill. From Drumglass north to

the Hensol Band of the Moffat Shales there are several rapid plications of the flaggy series (Division No. 1). The features of this series may be studied in the Parton Slate Quarries, where it has a reddish tint like the grits associated with it.

From Parton Station northwards to Moniaive (Sheet 9 of the Survey Map) massive (Queensberry) grits forming the dominant feature of the Tarannon Rocks, vary from two to ten feet in thickness and sometimes merge into bands of conglomerate. An excellent example of the latter rock is to be found on Craigenputtock Hill, where the pebbles consist of greywacke, grey shale, black shale, quartzite, quartz-schist, felsite, vein-quartz, &c. The most common ingredient is greywacke, the pieces measuring from eight to ten inches across. Next to the greywacke pebbles the fragments of quartzite and quartz-schist are the most numerous. In the presence of materials probably derived from the Highland region, the Craigenputtock conglomerate resembles that at Pinstane (p. 210). The pieces of black shale in this conglomerate contain fragments of *Dicellograptus* and *Diplograptus*.

In the northern portion of the Tarannon area between Loch Ken and Thornhill in Dumfriesshire, no zonal graptolites have been obtained from the few lenticular exposures of black shales in the midst of the coarse sediments. Neither have any determinable forms been procured from the sediments of younger date than the Moffat Shales. From certain dark films in the slates of the Marnhoul Quarries fragments of graptolites, which may probably belong to one or other of the Birkhill horizons, have been procured.

From Castle-Douglas southwards to Kirkcudbright Bay, and onwards to Gatehouse-of-Fleet, the massive (Queensberry) grits give place to a different series of strata (Hawick Rocks, Ardwell Beds), which consist of brown-crusted flags from three to six inches thick, with grey, green, and, in some instances, red shales. These are associated with brown, yellow, or ochreous greywackes from one to two feet thick. Frequently the shales are very fissile, splitting into thin laminæ. They often occur in zones from twelve to twenty feet in breadth. Though the dominant type of the series is flaggy, yet in certain areas bands of greywacke and grit can be traced for considerable distances. These usually break up into angular blocks. From the oxidation of their iron, the rocks weather with a brown crust to the depth of about half an inch, but on the fresh fracture they are grey or blue. Veins of quartz frequently traverse them, and their joints are often coated with carbonate of lime. Many of the flags and greywacke bands effervesce with acids.

The zones of shale throughout the area are more or less cleaved. On the west side of Kirkcudbright Bay, north of Bar Point, the direction of the strike is N. 35° E., while that of the cleavage is E. 23° N. Again, in the Borness cliffs, in the parish of Borgue, the direction of the strike is N. 36° E., and that of the cleavage about E. 30° N. The prevalent trend of

the cleavage-planes throughout the area is about E.N.E. and W.S.W.

The best section of the Hawick Rocks (Ardwell group) occurs on the shore between the mouth of the Fleet and the Meikle Ross, on the west side of Kirkcudbright Bay, where the innumerable plications of the strata may be seen to advantage, especially between Knockbrex and Kirkandrews Bays. So rapid are the folds that upwards of sixty anticlines and synclines have been mapped between Corseyard Point and Knockbrex, a distance of one mile and a quarter. Many of the folds are inverted. The presence of isoclinal folds in strata of such uniform lithological character shows how natural it is to exaggerate the thickness of these sediments by trusting merely to apparent superposition. Indeed, it frequently happens that, owing to the inclination of the axes of the folds in one general direction, the strata may seem to dip in unbroken sequence towards the same quarter for a considerable distance, while along the same line of strike at no great distance the anticlines and synclines may assume a normal character and show themselves by their divergent and convergent dip. For example, on the shore section on the west side of the estuary of the Dee, between the Doon and the base of the Wenlock Rocks, the strata are generally inclined to the south-west. But along the same line of strike round the shores of Falbogue and Brighouse Bays, onwards to the Borness cliffs, they rarely have a persistent dip in one direction. Yet there can be little doubt that they are as much folded in the one case as in the other.

Here, as elsewhere, the group of Hawick Rocks is singularly destitute of fossils. At Castle-Douglas Station, in the railway cutting at Halketleaths Mill, and on the east shore of Kirkcudbright Bay, about 300 yards north of Torr Point, *Protovirgularia Harknessi* has been obtained.

District West of the Cree.

The various sub-divisions of the Tarannon series can be traced across the "Rhinns" and "The Machars" of Wigtownshire. At one or two localities in this region fossils characteristic of the *Monograptus exiguus* zone have been collected. Thus, in the railway cutting to the north of Whaup Hill Station, where the strata approach the type of the Abbotsford flags, brown-crusted flags and shales dip north-west at high angles. They are surmounted by flags, shales, and greywacke bands, with occasional dark seams, from which the following graptolites have been obtained:

Monograptus exiguus (Nich.)
,, *Sedgwicki* (Portl.)
,, *Clingani* (Carr.)
Petalograptus palmæus (Barr.)
,, *folium* (His.)
Discinocaris or *Peltocaris*.

These fossils are in an imperfect state of preservation, more than half of the specimens collected being undeterminable.

Again, in the railway cutting near Baldoon Mains, on the south side of the Bladenoch, a thin band of shale interleaved in greywackes contains *Monograptus exiguus* and *M. convolutus*. In addition to these graptolites, specimens of *Protovirgularia* were procured from the beds on the north side of Garliestown Bay.

To the west of Luce Bay, the Tarannon Rocks may be traced across "The Rhinns" from Stoneykirk to the Mull of Galloway. In this area the lithological characters and relative distribution of the various sub-divisions of the Tarannon Rocks closely resemble those of the regions already described. Fortunately in one of the zones of shale which overlie the Moffat series, about two miles north of Drummore, graptolites were obtained indicating the horizon of the *M. exiguus* or *M. crispus* zone. These strata occur at Grennan, on the east coast, about sixteen miles to the south of Stranraer, where, on the slope adjoining the road leading to Drummore, a fine development of grey and blue shales has been quarried for slates. On the south face of the largest of the artificial openings, which has been excavated for some distance along the strike, the strata dip to the N.W. at angles varying from 65° to 70°. Here a seam, about an eighth of an inch thick, dark on a fresh fracture and bleaching white when exposed to weathering, is interleaved among the slates, and encloses in considerable abundance well-preserved specimens of *Monograptus exiguus* and *M. pandus*. At the roadside leading into this quarry, a form resembling *Monograptus crispus* was found among the debris. At the top of the rocky dip-slope, half way along the quarry, fine specimens of *Monograptus pandus* were collected in a thin dark film bleaching white, one of which measured 11½ inches in length.

On the rocky headland at the Mull of Galloway, and on the cliffs near St. Medans Cell, typical representatives of the Hawick Rocks occur. They consist of zones of fine grey and green mudstones and calmy shales, alternating with greywackes, which usually weather with a grey crust. Specimens of *Protovirgularia* have been found north of St. Medans.

CHAPTER XII.

II. THE NORTHERN BELT.

ARENIG, LLANDEILO, AND CARADOC FORMATIONS IN THE DISTRICT BETWEEN ABINGTON AND EDDLESTON.

We have now to consider the nature, development, and tectonic arrangement of the Silurian rocks which extend along what we have termed the Northern Belt of the Southern Uplands—that is, the long strip of ground which extends from the northern slopes of the Lammermuir Hills south-westwards through the Moorfoot and Leadhills across Upper Nithsdale and Carrick to the western coast of Loch Ryan and Portpatrick.

In order to show, in the first place, the relation of the volcanic rocks at the base of the Lower Silurian series to the radiolarian cherts and overlying black shales, we shall begin with certain typical sections where the sequence can be established. Some sections show the relations of the lavas and agglomerates to the cherts, others reveal the succession from the radiolarian cherts to the *Climacograptus caudatus* zone of the Hartfell black shales.

Basin of the Wandel Water.

About three miles to the north of Abington the Clyde receives an important tributary—the Wandel Water—which drains the high ground forming the watershed between the Clyde, the Tweed, and the Culter Water. The streams uniting to form the Wandel Water display more or less continuous sections of the volcanic series and the overlying sediments.

Hawkwood Burn.—One of the clearest sections is met with in the Hawkwood Burn (Figs. 42, 43), which joins the Wandel Water about 300 yards to the north of Birnock shepherd's house (north-east corner of Sheet 15 of the Survey Map). At the head of this stream, about three-quarters of a mile above its junction with the Wandel Water, and close to the heath-clad watershed between the Rome and Tewsgill Hills, the volcanic rocks occur in the midst of the cherts. On the west slope of the hollow cut out by this stream the rocks are comparatively bare and the sequence on the north side of the anticline is quite visible. In the centre of the fold lies a mass of volcanic agglomerate (1 Ts), dipping at a very high angle to the N.N.W. The breadth of the exposure, measured across the arch, a few yards up the west bank, is 26 feet; so that the actual thickness of the agglomerate

here is 13 feet. The matrix, dirty green in colour and highly decomposed, is made up apparently of finely divided igneous detritus, in which lie the volcanic blocks. The latter, sometimes rounded and sometimes elongated in form, and varying in size from one to several inches in diameter, consist chiefly of vesicular diabase.

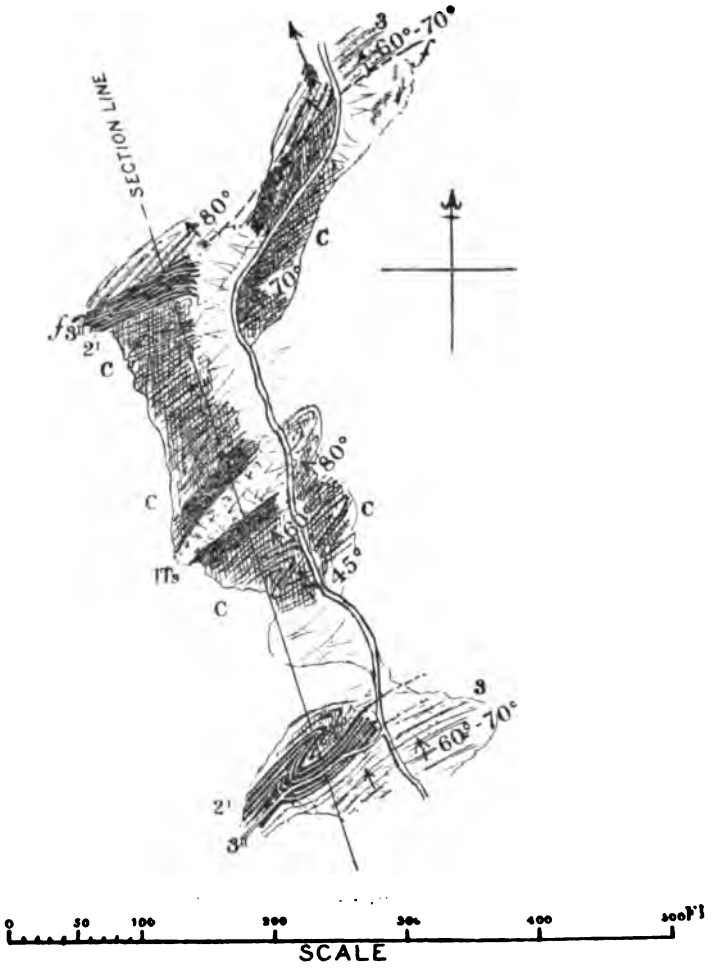


FIG. 42. —Plan of Strata, head of Hawkwood Burn, Wandel Water, Lanarkshire.

1Ts. Arenig lava and agglomerate. C. Radiolarian chert and shelly mudstones. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

On the north side the agglomerate is visibly overlain by the red cherts (C), their breadth of outcrop measuring 45 feet, followed by the grey chert zone, with shales and mudstones covering a

horizontal distance of 96 feet. Here this sub-division is evidently repeated by folds, for in other sections the measurements give a smaller thickness. Beyond the grey cherts, in a small scar on the west slope, some black shales yield fragments of Glenkiln forms in very poor preservation, and are abruptly truncated by a fault (*f*), bringing them into contact with greywackes and shales.

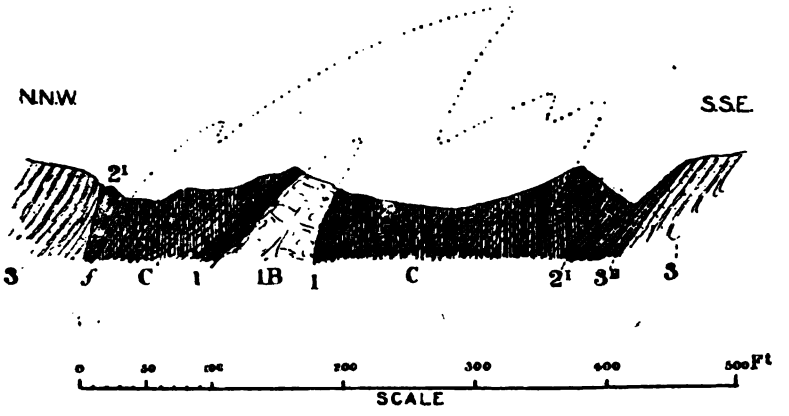


FIG. 43.—Section at the head of Hawkwood Burn, Wandel Water.

1B. Arenig lava and agglomerate. 1. Shelly mudstone (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

In the south limb of the fold the red cherts are seen in contact with the agglomerate, succeeded by red mudstones, but the grey cherts are buried underneath rock debris and vegetation. Beyond the covered area the black slates again appear with ill-preserved Glenkiln graptolites. On the east bank of the stream the agglomerate is exposed, evidently passing underneath the overlying cherts.

In the lower portion of this burn the radiolarian cherts and black shales appear in several folds among the shales, greywackes, and grits. In the sandy shales associated with the greywackes specimens of *Diplograptus foliaceus* have been obtained.

Back Grain, Ragged Gill.—A confirmatory section, showing the relation of the volcanic rocks to the overlying sediments, occurs in a streamlet on the north slope of Rome Hill, draining into the Ragged Gill—a tributary of the Wandel Water (Sheet 15 of the Survey Map). About 500 yards above its junction with the Ragged Gill, the Back Grain branches into two small streams. In the north branch, slaggy diabase-lava can be followed a short distance up the scar. Here a thin band of black shale, which has as yet proved unfossiliferous, immediately overlies the lava on both sides of the fold. Next in order come the various sub-zones of the radiolarian cherts, followed by the Glenkiln black shales with their characteristic fossils, forming the tops of the cliffs on both sides of the arch. Near the head of the streamlet the anti-

cline "noses out," and the overlying cherts form the crest of the fold. Towards the south the black shales are repeated by isoclinal folds, and the radiolarian cherts once more appear on another fold; while on the north, the diabase lava is exposed on another anticline. The evidence in this section plainly shows the infraposition of the diabase-lava with reference to the radiolarian cherts and black shales.

Rough Gill.—The sequence from the volcanic rocks into the Glenkiln-Hartfell black shales is further displayed in the Rough Gill, a streamlet joining the Birnock Burn in the extreme north-west corner of Sheet 16 of the Survey Map. Here three streams unite to form the Wandel Water, the Rough Gill, the streamlet draining a rocky hollow named the Deil's Barn Door, and the Birnock Burn. The first of these, lying furthest north, has, in the upper part of its course, cut a ragged gorge through the rocks now

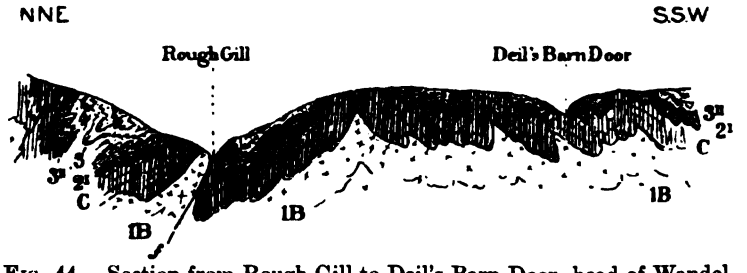


FIG. 44.—Section from Rough Gill to Deil's Barn Door, head of Wandel Water, Lanarkshire.

1B. Arenig lava. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

under consideration (Fig. 44). There the lava, an aphanitic diabase or altered basalt, is well exposed on the left bank of the stream forming the core of the arch (1 B). From an examination made by Dr. Hatch, this rock shows, under the microscope, a plexus of small lath-shaped felspars, the interstices of which are filled by alteration products (chlorite, calcite, &c.). The augite is completely decomposed, and there are a few small amygdules of calcite.

Towards the east end of the fold the breadth of the exposure of diabase is 48 feet. On the south side it is truncated by a small fault, with a downthrow to the south, bringing in a higher sub-zone of the cherts (C) with the overlying black shales. In the north-west limb the red cherts, decomposing in part, immediately overlie the diabase-lava succeeded by the higher zones. Here the red cherts measure 30 feet and the grey cherts 42 feet in thickness; giving a total thickness of 72 feet for the radiolarian cherts and mudstones.

The black shales overlying the cherts in this section have yielded the following forms, characteristic of the Glenkiln horizon:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
Lasiograptus bimucronatus (Nich.)
,, *Harknessi* (Nich.)
Climacograptus bicornis (Hall.)
Dicellograptus sextans (Hall.)
Corynoides sp.

About 300 yards to the south of the gorge known as the Deil's Barn Door this band of black shale is exposed in a highly convoluted form. In the lower part of the scar, near its junction with the Birnock Burn, the radiolarian cherts rise from underneath the black shales. Here the latter are fairly fossiliferous, and their organisms rather well preserved. It is important to note also that in this section specimens of *Climacograptus caudatus* have been obtained in abundance—a form confined exclusively to the Lower Hartfell Shales, and indicating a Lower Caradoc horizon. The following fossils were obtained from some of the zones in this gorge:

Diplograptus angustifolius (Hall.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
Climacograptus bicornis (Hall.)
Corynoides calycularis (Nich.)
Retiolites (Neurograptus) fibratus? (Lapw.)
Climacograptus caudatus (Lapw.)
Acrotreta Nicholsoni (Dav.)

This assemblage clearly proves that some of the higher seams in this band belong to the base of the Lower Hartfell black shales.

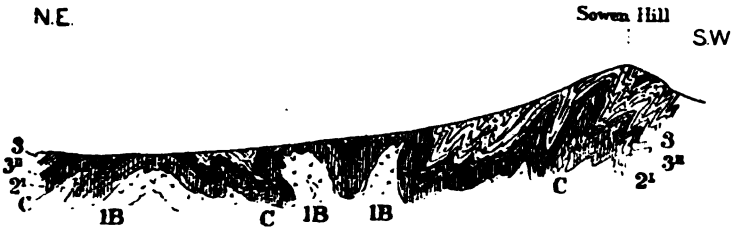


FIG. 45.—Section in Lead Burn, Wandel Water, Lanarkshire.

1B. Arenig lava. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc).

In the north-west corner of Sheet 16 of the Map, two streams, the Birnock Burn and the Deer Gill, running parallel with each other to join the Wandel Water, drain the northern slope of the watershed, while a third stream, the Lead Burn, also flows in the same direction. These three burns show transverse sections of the strata, the lowest beds exposed being the radiolarian cherts, followed by the Glenkiln-Hartfell black shales and the succeeding shales and greywackes. The probable prolongations of the same outcrops are indicated, though in such a highly convoluted area, where the folds die out so rapidly, the correlation of anticlines in different streams is a matter of uncertainty. These stream-sections show very clearly the extraordinary reduplication of the strata, and how a very limited thickness of beds may cover a broad area.

The Lead Burn has a fall of 500 feet in three-quarters of a mile (Fig. 45). At the mouth of the stream the rocks are buried under boulder clay; but about 300 feet higher up the cherts appear. Here their upper bands are particularly massive, insomuch that they have been used for building dykes. About 500 yards from

the foot of the stream a massive band of black shales occurs (Glenkiln-Hartfell), which, after being succeeded by greywackes and shales, again emerges further up, but owing to inversion it appears to overlie the greywackes. Beyond this point the cherts and black shales alternate, till at the 1250-feet contour line they are followed by the greywackes and shales, dipping at steep angles to the north. The latter must be folded rapidly on themselves, for at least two anticlines of black shale with the underlying cherts can be traced from the Sowen Hill, along the watershed in the strike of these greywackes and shales.

In the Deer Gill no rock is exposed for about 150 yards up stream until the cherts appear, and for a distance of 400 yards are constantly repeated by the folds, which are well seen on the banks. About 600 yards from the foot of the burn the Glenkiln-Hartfell black shales succeed, with a S.S.E. dip, and plunge underneath the overlying grey shales and greywackes. Beyond this point the black shales reappear in several folds, one of which reveals the underlying cherts.

At the foot of the Birnock Burn, and just above the point where it is joined by the Rough Gill, the Glenkiln-Hartfell black shales make their appearance, while the radiolarian cherts are visible a few yards off on the south-west bank. Here the following fossils have been obtained:

Didymograptus superstes (Lapw.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
,, *caudatus* (Lapw.)

The outcrop of this band is much in the same line of strike as that in the Deil's Barn Door, where, as already indicated, *Climacograptus caudatus* also occurs.

Descending the Wandel Burn to a point about 200 yards above its junction with the Deer Gill, we again come upon the black shales on the north bank of the stream, where they have yielded the fossils enumerated in the accompanying list:

Diplograptus angustifolius (Hall.)
,, *mucronatus* (Hall.)
Dicranograptus ramosus (Hall.)
Climacograptus sp.
Hyalostelia fasciculus (M'Coy.)

The same outcrop of black shale can be followed along the north bank to the mouth of the Deer Gill, where the beds are inclined to the N.N.W., and the radiolarian cherts succeed on the north side with an inverted dip. This exposure has given the following assemblage of Glenkiln-Hartfell fossils:

Diplograptus mucronatus (Hall.)
,, *angustifolius* (Hall.)
,, *foliaceus* (Murch.)
Climacograptus cœlatus (Lapw.)
,, *bicornis* (Hall.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Amphigraptus sp.
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)
Hyalostelia fasciculus (M'Coy.)

On the south bank of the Wandel Burn, just above the mouth of the Deer Gill, a thin seam of black shale, containing small *Diplograpti* in great numbers, occurs among greywackes and shales.

Rein Gill.—At a point about a third of a mile above the shepherd's house at Birnock, the Wandel Burn receives from the north a small tributary named the Rein Gill (Sheet 15). The section exposed in the lower part of this gill is of importance, from the abundance and good preservation of the fossils. Owing to the highly convoluted and shattered condition of the black shales in this northern area, it is often difficult to get a good assemblage of fossils to prove their horizon, and even more difficult to sub-divide them into sub-zones. From this exposure, however, a large collection has been obtained, which has been equalled in this district only by the fine assemblage from the outcrops at the foot of Hawkwood Burn to be described presently. These organisms are given in the following list:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *nitidulus* (Lapw.)
Dicranograptus formosus (Hopk.)
,, *zic-zac* (Lapw.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
Dicellograptus patulosus (Lapw.)
,, var. *B.* (Lapw.)
,, *sextans* (Hall.)
,, *intortus* (Lapw.)
,, *elegans* (Carr.)
,, *moffatensis* (Carr.)
Climacograptus bicornis (Hall.)
Climacograptus peltifer (Lapw.)
,, *tridentatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus angustifolius (Hall.)
,, *foliaceus* (Murch.)
,, *euglyphus* (Lapw.)
,, *perexcavatus* (Lapw.)
Lasiograptus margaritatus (Lapw.)
,, *Harknessi* (Nich.)
,, *bimucronatus* (Nich.)
Glossograptus Hincksi (Hopk.)
Acrotreta Nicholsoni (Dav.)
Acrothele granulata (Linn.)
Hyalostelia fasciculus (M'Coy.)

From this list it is apparent that the band of shale at the foot of the Rein Gill contains some forms exclusively confined to the Glenkiln Shales of the Moffat area, and some which occur in that division and part of the Lower Hartfell Shales. From the abundance of the form *Dicranograptus ramosus* in one of the seams it would almost appear as if the passage beds between the Glenkiln and Hartfell divisions were represented. *Climacograptus bicornis* and its varieties are particularly abundant and well preserved in this section.

The black shales containing this assemblage of fossils are the first rocks met with in the ascent of the stream. The locality is about 100 yards from the junction of the Rein Gill with the Wandel Water. The beds occur on the north bank and also in the channel of the burn, where, with an inverted dip, they plunge underneath the radiolarian cherts. Proceeding up the burn the observer crosses the cherts and finds another outcrop of the black shales yielding *Diplograptus angustifolius, D. foliaceus, Cryptograptus tricornis, Acrotreta Nicholsoni, Hyalostelia fasciculus.*

Wandel Water.—In this stream, about 200 yards below its junction with the Rein Gill, the radiolarian cherts and associated black shales again appear. From some of the seams in

the latter, specimens have been obtained of *Diplograptus angustifolius*, *Dicranograptus ramosus*, *Climacograptus bicornis*, *Corynoides calycularis*. At the point where the Wandel Water is joined by the Hawkwood Burn an excellent exposure of the Glenkiln black shales supplies graptolites in profusion and in great variety. No less than seven genera, including eleven species, were counted on one small slab. The shales are finely banded, and split into thin laminæ under the hammer. On the south side they are in immediate contact with the greywackes and shales, but to the north the succeeding strata are obscured. The subjoined list enumerates the organisms obtained at this locality:

Didymograptus superstes (Lapw.)
,, *serratulus* (Hall.)
Thamnograptus typus (Hall.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *explanatus* (Lapw.)
,, *nitidulus* (Lapw.)
Dicranograptus formosus (Hopk.)
,, *zic-zac* (Lapw.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
Glossograptus Hincksi (Hopk.)
Lasiograptus margaritatus (Lapw.)
,, *bimucronatus* (Nich.)
Dicellograptus patulosus (Lapw.)
,, ,, var. *B.* (Lapw.)
,, *moffatensis* (Carr.)
,, *divaricatus* (Hall.)
,, *sextans* (Hall.)
,, *intortus* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus mucronatus (Hall.)
,, ,, very large form.
,, *perexcavatus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *tridentatus* (Lapw.)
Acrotreta Nicholsoni (Dav.)

At this locality *Didymograptus superstes* is especially abundant, as well as *Cryptograptus tricornis*. It is deserving of note that the typical Lower Hartfell graptolite *Climacograptus caudatus*, which, as already indicated, occurs in the black shales at the Deil's Barn Door, at the head of the Wandel Water, has not been found in this section, though the succeeding greywackes and shales are visibly in contact. It is not improbable that this fold of the black shales lies to the north of the limit of the typical Lower Hartfell graptolites; though some of the forms found at the foot of Rein Gill not far to the south still indicate an assemblage commonly associated with the lower zones of the Lower Hartfell black shales.

Wallace's Cast, Wandel Water.—Having now described the sequence of strata from the Arenig volcanic rocks and overlying radiolarian cherts to the Glenkiln-Hartfell black shales, we shall refer to the sediments which succeed these graptolite-bearing bands.

Attention has already been directed to the occurrence of *Diplograptus foliaceus* in grey sandy shales associated with the greywackes near the foot of the Hawkwood Burn, opposite the shepherd's house at Birnock. The section in the Wandel Water to the north of the outcrop of black shales at the foot of Hawkwood Burn is of special interest from the occurrence of a highly fossiliferous zone in the ordinary sediments, at Wallace's Cast (Sheet 15 of the Map). At a distance of 300 yards north from the foot of Hawkwood Burn, on the east bank, brown shales are visible, and after another short break in the section the fossiliferous zone is met with on the same

side of the stream. This important band consists of fine grey shale, containing calcareous nodules and lenticular masses of pebbly grit. The fossils occur chiefly in the limestone nodules, which decompose readily by weathering; some are found in the shales and some in the pebbly grit. The limestone nodules are not derivative. Now, though no continuous visible section reveals the relations of this bed to the Glenkiln black shale, there cannot be any doubt that these fossiliferous sediments overlie the Glenkiln beds. The accompanying generalised section (Fig. 46) from Rome Hill, across the basin of the Wandel Water to Wallace's Cast, shows the relative position of the various sub-divisions of the Llandeilo-Bala Rocks. The following list of fossils shows that the strata at Wallace's Cast are referable to the Bala or Caradoc formation. Indeed, it is highly probable that part of the Lower Hartfell black shales is there represented. The fossils are chiefly casts, but they are in fair preservation and easily determinable:

Nidulites favus (Salter.)
Petraia bina (Lonsd.)
Lindströmia (Petraia) subduplicata (M'Coy.)
Stenopora (Favosites) fibrosa (Goldf.)
Glyptocrinus basalis (M'Coy.)
Encrinurus punctatus (Brünn.)
Phacops Brongniarti (Portl.)
Illænus latus (M'Coy.)
Remopleurides laterispinifer (Portl.)
Lingula attenuata (Sow.)
Orthis calligramma (Dalm.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, ,, *testudinaria* (Dalm.)
,, *vespertilio* (Sow.)
Strophomena corrugatella (Dav.)
,, (*Rafinesquina*) *deltoidea* var. *rotundata* (Conrad.)
,, *grandis* (Sow.)
Strophomena (*Orthis*) *kilbuchoensis* (Dav.)
,, *rhomboidalis* (Wilck.)
Leptæna sericea (Sow.)
,, ,, var. *rhombica* (M'Coy.)
,, (*Christiania*) *tenuicincta* (M'Coy.)
,, *transversalis* (Wahl.)
Rhynchonella Stricklandii (Sow.)
,, *borealis* (?) (Schl.)
Pleurotomaria (Raphistoma) elliptica (His.)
,, ,, *lenticularis* (Sow
,, *alata* (Wahl.)
Murchisonia gyrogonia (M'Coy.)
Maclurea macromphala (M'Coy.)
Bellerophon acutus (Sow.)
,, *dilatatus* (Sow.)
Conularia elongata (Portl.)
Pterotheca corrugata (Salter.)

To the north of the outcrop of fossiliferous shale and grit at Wallace's Cast, grey shales with occasional greywackes are repeated by isoclinal folds.

Abington District East of the Clyde.

In the Abington district lying to the south-west of the basin of the Wandel Water, and to the east of the river Clyde, the Arenig lavas and overlying Llandeilo Rocks are exposed in various folds. To the east of the village of Abington, the Raggen Gill, which flows towards the Clyde and drains the slopes of the Tewsgill and Arbory Hills, displays a section of the volcanic zone and overlying sediments. In this stream the radiolarian cherts are exposed at the bend about half a mile above the railway to the south of Arbory Hill. Traced up the water-course, they seem to be repeated by

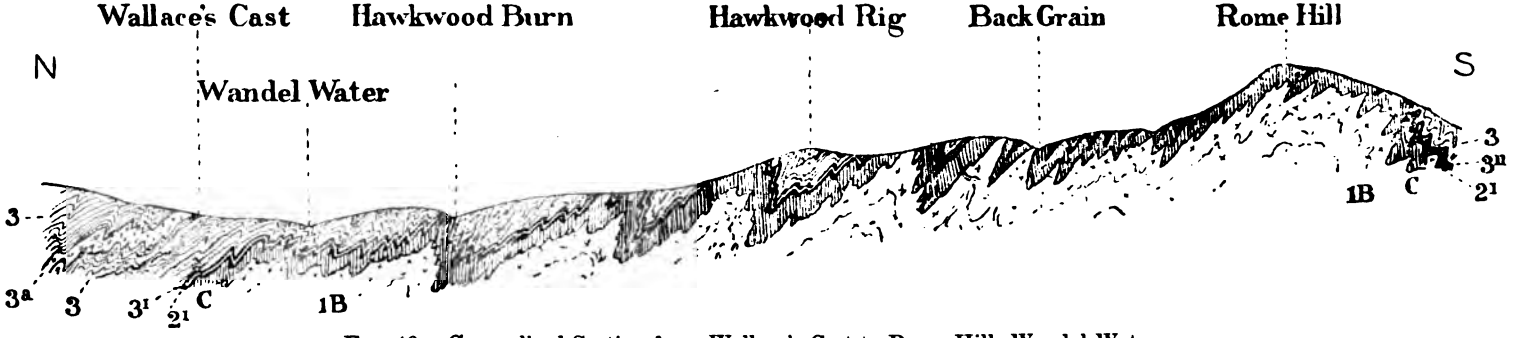


FIG. 46.—Generalised Section from Wallace's Cast to Rome Hill, Wandel Water.

1B. Arenig lava. C. Radiolarian chert. 2I. Glenkiln Shales. 3II. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). 3a. Fossiliferous conglomerate and shale (Caradoc).

folds, but within a short distance debris of black shales is found on the north bank, with fragments of graptolites, indicating the position of the Glenkiln band. Towards the south, radiolarian cherts again appear, with greywacke probably lying in a fold, but eventually they give place to the volcanic zone, represented here by compact diabase or altered basalt. Under the microscope the rock shows plagioclase felspar in small lath-shaped crystals, brown augite in granular and ophitic masses, with serpentinous pseudomorphs after olivine. It occurs in several folds with intervening cherts, but towards the upper limit of the section the radiolarian cherts are succeeded by a band of black shale and greywackes and shales (Fig. 47). The general dip of the strata in this section being towards the north-west, the folding is isoclinal. Unfortunately the black shales are so shattered that it is impossible to prove their horizon satisfactorily by fossil evidence. The only forms obtained are *Diplograptus angustifolius, Climacograptus, Acrotreta Nicholsoni.* At the northern limit of the section, on Arbory Hill, grey grits occur, which are supposed to be on the same horizon as the fossiliferous grits of Duntercleuch, Lead Hills (Fig. 47).

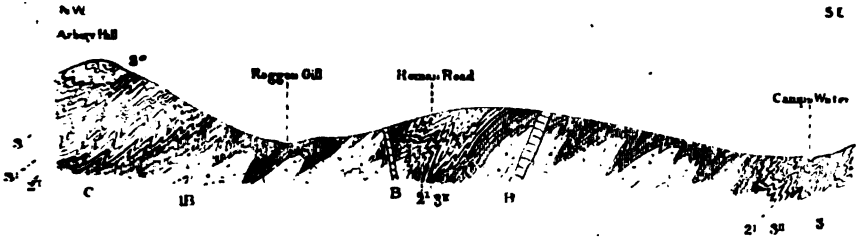


FIG. 47.—Section from Arbory Hill to Camps Water, Clydesdale.

1B. Arenig lava. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). 3a. Fossiliferous conglomerate (Caradoc). B. Dolerite dykes (Tertiary).

Coldchapel Burn.—In the Coldchapel Burn, which joins the Clyde about a mile north of Abington, several folds lay bare the radiolarian cherts and black shales. At the bend about a mile and a half above the foot of the stream, the black shales have yielded *Diplograptus perexcavatus, C. bicornis* var. *peltifer, Diplograptus mucronatus, Dicranograptus ramosus, Acrotreta Nicholsoni.*

Southwood Burn.—On the hill slope east of Abington House, the south-west prolongations of the folds reveal the lavas and cherts near the head of Raggen Gill and Coldchapel Burn just described. Here two small burns unite to join the Clyde opposite Abington House. One of these, represented on the 6-inch map as discharging separately into the Clyde at Southwood, is now a tributary of the other or Wintercleuch Burn. Not far above the junction of the two streams a small exposure may be seen of pillowy lava associated with the grey cherts. Further up stream the red cherts appear, followed by similar lava and cherts, which are in

turn succeeded by a broad mass of coarse ophitic dolerite or gabbro intrusive in the Arenig lava. The relation between the two is displayed on a knob of rock on the north bank of the burn, measuring about eight feet broad and three feet high. Near the head of the stream the volcanic rocks are succeeded by the cherts and black shales repeated by folds.

FIG. 48.—Section, Southwood Burn, Abington, Clydesdale.

1B. Arenig lava. C. Radiolarian chert. 2i. Glenkiln Shales. 3ii. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). B. Dolerite dyke (Tertiary).

Wintercleuch Burn.—For some distance from the railway no rock is visible in this burn, which is nameless on the 1-inch map. About 100 yards above the junction of the two burns the first rock met with consists of coarse dolerite, showing under the microscope much altered felspar and fresh augite. By means of small knobs on the hill slope this coarse-grained intrusive rock can be traced for 400 yards in a south-west direction to the alluvial terraces of the Clyde opposite the foot of Glengonner Water. Higher up the stream the lavas and cherts are repeated by compound folds. Along the strike of these higher folds there is evidence of the development of flaser structure in the lava by mechanical movement. About 170 yards to the W.S.W. of the Wintercleuch Burn, on the north side of a knoll of rock about ten yards broad, near the 1000-feet contour line, the normal diabase-lava is exposed, the pillowy masses measuring in some instances nine inches by seven inches; while the remaining portion shows the same material deformed. In places the nodular masses are flattened, elongated, and surrounded by a schistose matrix; in other parts they disappear, and the rock merges into a green schistose diabase or chlorite-schist. Near the head of the Wintercleuch Burn, the Arenig lava is succeeded by radiolarian cherts, black shales, greywackes, and shales.

Castle Hill, Abington.—Southwards from Abington along the eastern slope of the Clyde valley, a considerable development of Arenig volcanic rocks and radiolarian cherts may be observed to the north-east of Kirkton. These exposures are interesting, since it is possible to connect the lavas and cherts with the fossiliferous band of black shales seen on the slope near the railway cutting, and hence with the important band in that

cutting to be presently described. The accompanying section (Fig. 49) is drawn across the brow of the hill in a N.N.W. and S.S.E. direction. At the north-west termination various folds of the cherts (C) and black shales (2^{1}, 3^{II}) appear with greywackes and grits (3). At the old Fort or Camp, marked on the map, the greywackes on the south side of the arch are brought into contact with the cherts, without the black shales intervening. The first appearance of the lava represented in section is about 170 yards to the south of the Camp, while another outcrop, not in the line of section, occurs a little distance to the north of this

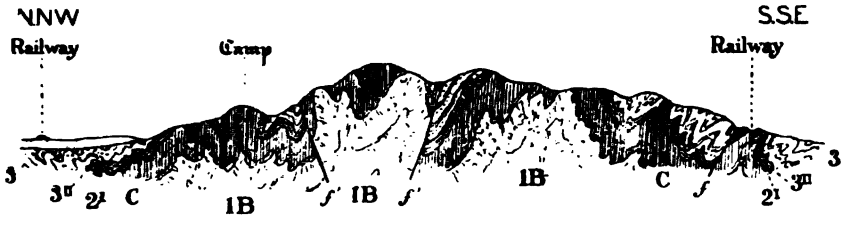


FIG. 49.—Section, Castle Hill, Abington, Clydesdale.

1B. Arenig lava. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

point. The main exposure, however, is found about 300 yards to the south of the Camp, where it stretches up the hill slope with an average breadth of forty yards, bounded on the north side by the radiolarian cherts. The southern limit is marked by a grassy hollow, which is probably a line of fault, as greywackes immediately succeed. An interesting feature is observable in connection with the volcanic rock; the surface facing the grassy hollow is nodular or brecciated, as if the cooled skin or upper surface had cracked up into pieces which were enveloped in the still molten lava.

Southwards black shales and radiolarian cherts are followed still further south by three small isolated masses of lava, forming inliers in a mass of Arenig cherts. Along the southern margin of these cherts, from a fine exposure of black shales, the following characteristic Glenkiln forms have been collected at a point about 200 yards N.N.E. of the railway cutting opposite Kirkton:

Cœnograptus gracilis (Hall.)
,, *nitidulus* (Lapw.)
Didymograptus superstes (Lapw.)
Dicranograptus formosus (Hopk.)
,, *minimus* (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Diplograptus foliaceus (Murch.)
,, *mucronatus* (Hall.)
Climacograptus bicornis (Hall.)

On the southern slope of Castle Hill eastwards to Southwood Rig, a belt of ground upwards of half a mile in width is composed mainly of plicated Arenig cherts, with black shales forming the outer margins of the folds. The hill slopes are

strewn with debris of the radiolarian cherts, and the black shales are visible, sometimes in scars and sometimes in small burns flowing into the Camps Water. Indeed, from the constant repetition of these two zones it is apparent that the strata, though covering so great a breadth of ground, are of no great thickness and have been subjected to much plication. Of the various exposures of black shales the most interesting is to be found in the railway cutting about a mile and a quarter south of Abington.

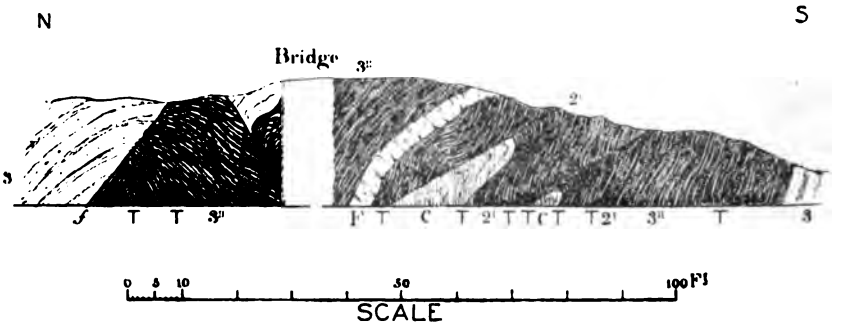


Fig. 50.—Section, Railway Cutting opposite Kirkton, Abington, Clydesdale.

C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). F. Felsite dyke. f. Fault. T. Thrust faults.

This section shows the extraordinary disturbed character of these black shale outcrops where they can be studied in detail. The bands are traversed by a series of faults, normal and reversed, which renders an examination of the beds by the zonal method a matter of great difficulty. In the Abington area the strata are frequently so crushed and shattered that fossils are not easily obtained from them.

In the centre of the section, to the south of the railway bridge, a small exposure of the radiolarian cherts is truncated by faults on both sides. North of the bridge the greywackes and shales are brought into contact with the black shales by a fault. The following forms were obtained from this section:

Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Dicellograptus sextans (Hall.)
Diplograptus mucronatus (Hall.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus Forchhammeri (Gein.)
,, ,, var. *flexuosus* (Lapw.)
Dicellograptus intortus (Lapw.)
,, *elegans* (?) (Carr.)
Lasiograptus margaritatus (Lapw.)
,, *Harknessi* (Nich.)
Amphigraptus radiatus (Lapw.)
Dicranograptus ramosus (Hall.)
Corynoides nov. sp.
Acrotreta Nicholsoni (Dav.)

It is clear that graptolites common both to the Glenkiln and the Lower Hartfell zones are met with in this section. Indeed, this

assemblage of species proves that some of the bands at least represent the base of the Lower Hartfell black shales. This supposition is confirmed by the evidence obtained in a quarry at the road-side close to the railway cutting. There the prolongation of the band just referred to is visible, and the section further shows a passage upwards into the greywackes and shales. From one of the thin seams of black shale, which are partly dark sandy shales, in this quarry, excellent specimens of *Climacograptus caudatus* have been gathered. The palæontological evidence indicates that the highest zone represented is intermediate between the *Pleurograptus linearis* zone and the *Climacograptus Wilsoni* zone. It is interesting, too, to observe that this evidence is in accordance with that found in the section at the Deil's Barn Door at the head of Wandel Water.

The following is the list of fossils obtained from the quarry beside the railway cutting:

Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Diplograptus mucronatus (Hall.)
,, *perexcavatus* (Lapw.)
Glossograptus Hincksi (Hopk.)
Corynoides calycularis (Nich.)
Acrothele granulata (Linnr.)

When the collection of graptolites was made from the section in the railway cutting, only some of the seams proved fossiliferous; had the band in contact with the radiolarian chert yielded fossils they would probably have belonged to the Glenkiln horizon.

Whelphill Grains.—About two miles to the south-east of Abington, the Clyde receives two tributaries on its right bank, the Camps Water and Midlock Water. Various exposures of black shale are visible at intervals along a line traceable from Whelphill on the Midlock, by Grains on the Camps Water (Sheet 16), across the boundary between the counties of Lanark and Peebles, onwards to the sources of the Holms Water above Glencotho. It is highly probable that some of these may occur on separate inverted folds, and that they may not be prolongations of one and the same continuous outcrop. The black shales occur in grey sandy shales (Lowther Shales) and grits, the beds having a general inclination to the north-west. Several local isoclines of black shale are found near the main folds, as, for example, in the Grains Burn—a tributary of the Camps Water, and the Back Burn south of Culter Waterhead. Owing to the highly contorted and shattered character of most of these black shales, few fossils have been obtained from them. At Whelphill they have supplied *Dicellograptus moffatensis* much distorted, *Diplograptus foliaceus*, and *Climacograptus*; at Grains they have afforded *Dicellograptus Forchhammeri*, *Climacograptus bicornis*, and *Corynoides calycularis*.

In a small tributary of the White Gill, named the Reeve Sike, between Whelphill and the Grains, radiolarian cherts are exposed with the black shales. Again in the Grains Burn, about 440 yards above the Grains shepherd's house, an exposure of black

shales on the right bank of the stream furnished the following forms:

Leptograptus flaccidus (Hall.)
Diplograptus foliaceus (Murch.)
Retiolites (Neurograptus) fibratus (Lapw.)
Glossograptus Hincksi (Hopk.)
Dicellograptus moffatensis (Carr.)
Cryptograptus tricornis (Carr.)
Climacograptus sp.
Siphonotreta micula (M'Coy.)

The area between the great complex assemblage of volcanic rocks, radiolarian cherts, and black shales at the head of the Wandel Water and the Whelphill band, about two miles to the south-east, is occupied by a folded series of greywackes and shales with bands of grit and occasionally of conglomerate which have hitherto proved unfossiliferous. In a band of conglomerate in the Back Burn, about half a mile up stream from Culter Waterhead, fragments of chert with radiolaria occur.

The strip of ground between the Whelphill outcrop of black shales and the line marking the base of the Llandovery Rocks in Sheet 16 is occupied by a development of grey and blue shales weathering frequently into a brown or buff colour. Where a fresh fracture can be got they often contain minute specks or spots due to an iron carbonate, the decomposition of which gives rise to the brown tint (Lowther Shales). They are associated with greywackes and pebbly grits, which, however, form a minor feature of the series. Their notable characteristic is the occurrence of nodules of limestone embedded in the shales. Sometimes they coalesce, forming a continuous line of nodules. Occasionally thin ribs of limestone are interleaved in the shales associated with calcareous grits that yield traces of fossils. The limestone nodules can be traced in Sheet 16 of the map for some distance. They appear in a small burn about three-quarters of a mile to the east of Whelphill, and again in a stream on the east slope of Midge Hill. Beyond the Camps Water, they can be traced from the head of the Fair Burn to the source of the Whitelaw Burn, on the watershed south of Coomb Dod. They reappear on the north-west of the Kingledores Burn, on the slope of the Coomb Hill. At some of these localities, as, for instance, at the head of Fair Burn, Camps Water, the calcareous grit occurs in connection with the nodules of limestone. There can be no doubt that these calcareous nodules and grits represent the well-known Wrae limestone to be described presently. The shales with which they are associated are regarded as the equivalents of the Barren Mudstones of Moffat.

Culter Water District.

To the north-east of the complicated area in the upper reaches of the Wandel Water a similar development of Arenig volcanic rocks and overlying sediments may be seen in the various streams that unite to form a tributary of the Culter Water at Birthwood, about two miles south of Culter. Several of these streams rise

on the north slope of the watershed in the north-west corner of Sheet 16. On referring to that map it will be seen that a conspicuous arch of diabase-lavas and tuffs, with the associated radiolarian cherts and black shales, occurs on the watershed, extending eastwards to Duncan Gill and passing into Sheet 24. Attention will be directed first to the sections at the head of these streams connecting the geological structure of the Wandel Basin with that of Culter Water.

Duncan Gill.—From the section in the upper part of Duncan Gill, where its course is north-east and parallel with that of the Birnock Burn, important evidence has been obtained. In a scar on the west bank of the stream, in a line with the gorge of the Deil's Barn Door (*ante* p. 221), and separated from it only by a few yards, the radiolarian cherts with the basal red zone are visible at the bottom of the gully. The black shales which then succeed may be traced almost continuously to the Deil's Barn Door section. The graptolites obtained from Duncan Gill include excellent specimens of *Climacograptus caudatus*, showing that the Lower Hartfell horizon is represented in this part of the Culter Basin.

Further up the stream, the radiolarian cherts are repeated on successive anticlines overlain by the Glenkiln-Hartfell black shales. In the outcrop of black shales in Duncan Gill, 300 yards south of the scar just referred to, *Climacograptus caudatus* occurs with other graptolites. Nearer the watershed at Duncan Gill Head this band is succeeded by shales and coarse grits, forming part of the Caradoc formation of this region. The accompanying section (Fig. 51) shows the extraordinary folding of the rocks. At the north end of the tract illustrated by this section (Sheet 24 of the Survey Map), greywackes and shales form the high ground, but the Glenkiln-Hartfell Shales come to the surface north of Mere Cleuch, and are repeated by various folds as far as the Eastside Burn. In this stream, at the point where it is joined by the Duncan Gill (on the south margin of Sheet 24), the black shales are seen near the volcanic rocks. Here, on the further side of a fault, a fine exposure of diabase-lava runs for a distance of 150 yards along an isoclinal fold. This inlier of the volcanic rocks is one of the largest in the basin of the Culter Water, since it can be traced for a mile from the Eastside Burn (Sheet 24), south-west by the head of Big Sma'gill, to the watershed at the sources of the Wandel Water (Sheet 16). The main mass is composed of highly amygdaloidal aphanitic diabase (altered basalt), which is much decomposed. The augite is completely altered into chlorite, and the amygdules are filled with calcite. Round the western end of the fold a band of tuff overlies the lava, and is succeeded on the south side by the radiolarian cherts.

The section which continues southwards towards the head of Duncan Gill displays a constant repetition by isoclinal folds of the radiolarian cherts and Glenkiln-Hartfell black shales without exposing the volcanic zone. It is interesting to note, in connection with the wonderful corrugation of the beds in this

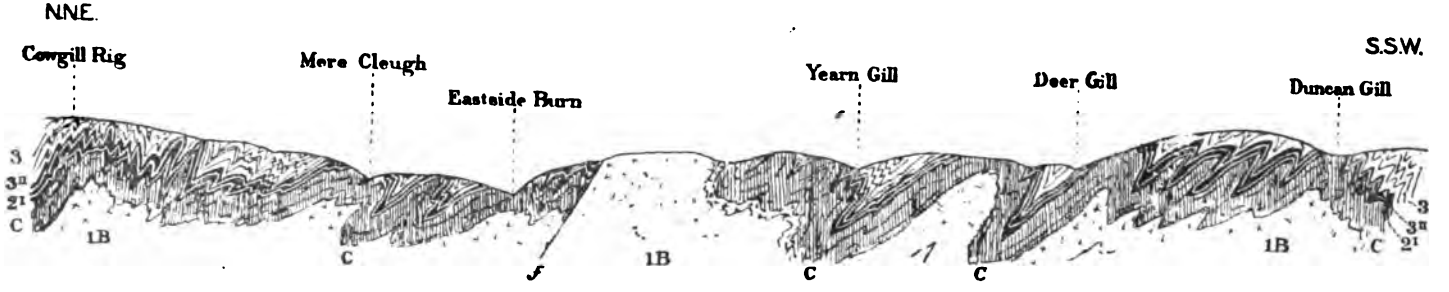


FIG. 51.—Generalised Section, Cowgill Rig to Duncan Gill, Culter Water, Lanarkshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

area, that near the head of Deer Gill—a tributary of Duncan Gill—while the cherts are visible in the bottom of the gorge in continuous section, the outcrop of the overlying black shales can be traced along the top of the west bank repeated by numerous folds (Sheet 16, north-east corner).

Big Sma'gill.—At the south end of the section in Big Sma'gill that unites with Eastside Burn to form Cow Gill the arch of diabase-lava with overlying tuff is met with, being the western prolongation of the fold just described at the mouth of Duncan Gill. Owing to a fault, the normal sequence of the cherts is not visible. To the north of the volcanic rocks succeed shales and grits with a bed of conglomerate. A thin band of black shales rapidly appears, followed by shales and pebbly grits. Here for a distance of 100 yards rapidly folded black shales may be observed, which have yielded *Climacograptus bicornis*, *Diplograptus*, *Corynoides calycularis*, and *Siphonotreta micula*. By a series of isoclinal folds these black shales are repeated with a persistent dip to the N.N.W., and evidently it is chiefly the higher seams that are represented. Northwards, the overlying shales and grits again appear, followed by another fold of the Glenkiln Shales dipping towards the south.

Shank Houp.—This stream, which runs north to join the Cow Gill about a mile west of Birthwood, on the Culter Water, has a course roughly parallel with that of the Eastside Burn, and exposes a transverse section of the strata. Although it has not laid bare any of the volcanic rocks it reveals the radiolarian cherts on two anticlines, together with the Glenkiln black shales and overlying sediments. Eastwards, along the strike of these folds in the Culter Water, the radiolarian cherts and black shales "nose out," and the anticlines are represented in higher beds, composed of the overlying grits, greywackes, and shales. Thus as we follow the anticlines from the sources of the Wandel Water to the tributaries of the Culter Water we gradually pass to higher zones. It is reasonable, therefore, to infer that the Caradoc beds are quite as much folded as the underlying Arenig and Llandeilo rocks, though from the absence of recognisable zones it is difficult to prove it.

Woody Cleuch.—On the north slope of Woodycleuch Dod, a small stream flows into the Shank Houp, which, near the foot, displays the diabase-lava. No rock is visible on the north side of the diabase, but to the south the red nodular cherts immediately succeed, followed by the higher zones and the black shales. By means of isoclinal folds the cherts and Glenkiln black shales reappear, followed towards the south by the greywackes and shales.

We shall now describe a group of sections on the west side of the Culter Water, near the margin of the tableland, and within a mile and a half of the great fault that brings the Old Red Sandstone volcanic rocks into conjunction with the Silurian strata.

Key Gill.—About a mile and a half to the south-west of Birthwood, on the Culter Water, in a streamlet named the Key Gill, which joins the Cow Gill about 400 yards below the shepherd's

house of that name (Fig. 52), an excellent exposure of the strata shows their sequence from the radiolarian cherts to an important band of conglomerate, which is regarded as the south-west prolongation of the fossiliferous grit at Kilbucho. This may be regarded as the type-section for this part of the Culter Water basin.

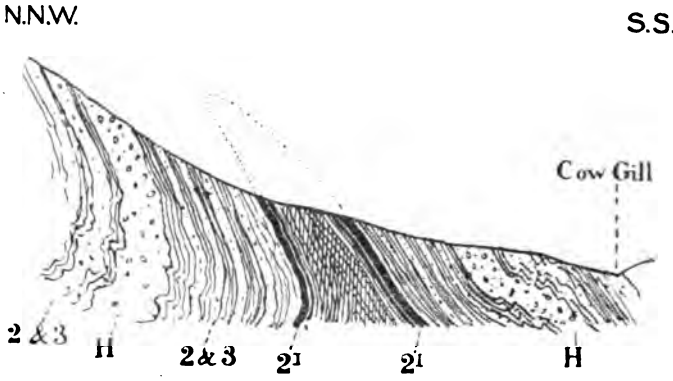


FIG. 52.—Section in Key Gill, tributary of Cow Gill, Culter Water, Lanarkshire.

2¹. Glenkiln Shales. 2. Llandeilo series. 3. Caradoc series. H. Pebbly grit, fossiliferous.

The strata are here arranged in an isoclinal fold dipping towards the S.S.E. In the centre lie the cherts, succeeded immediately by the Glenkiln black shales (2¹), followed by grey sandy shales with greywackes (2 & 3). These are overlain in turn by a band of conglomerate and grit (H) representing the horizon of the Kilbucho grit. On the north side of the isocline the outcrop of this bed is a little further distant from the centre of the arch than that on the south side. In its lithological character and modes of weathering this grit closely resembles the fossiliferous grit of Kilbucho to be described in the sequel. It also contains fragments of fossils. A glance at the map will show that the bands of fossiliferous grit on the south slopes of Lamington Hill and Howegill Rig lie much in the same line of strike as the well-known bed at Kilbucho, the various outcrops being due to folds.

On the road between Cow Gill and Lamington House, south-west of Key Gill, an anticline of the radiolarian cherts is locally known as the Giant's Grave. To the west of this exposure, near a small loch, an outcrop of black shales has yielded *Climacograptus peltifer*, *Dicellograptus sextans*, *D. divaricatus*, and *Corynoides calycularis*.

Howe Gill.—About half a mile to the east of Key Gill an interesting section is visible in the Howe Gill, which drains the hollow between the Lamington Hill and Howegill Rig (Fig. 53). Three successive anticlines expose with great clearness the radiolarian cherts, including both their red and grey sub-zones. In the

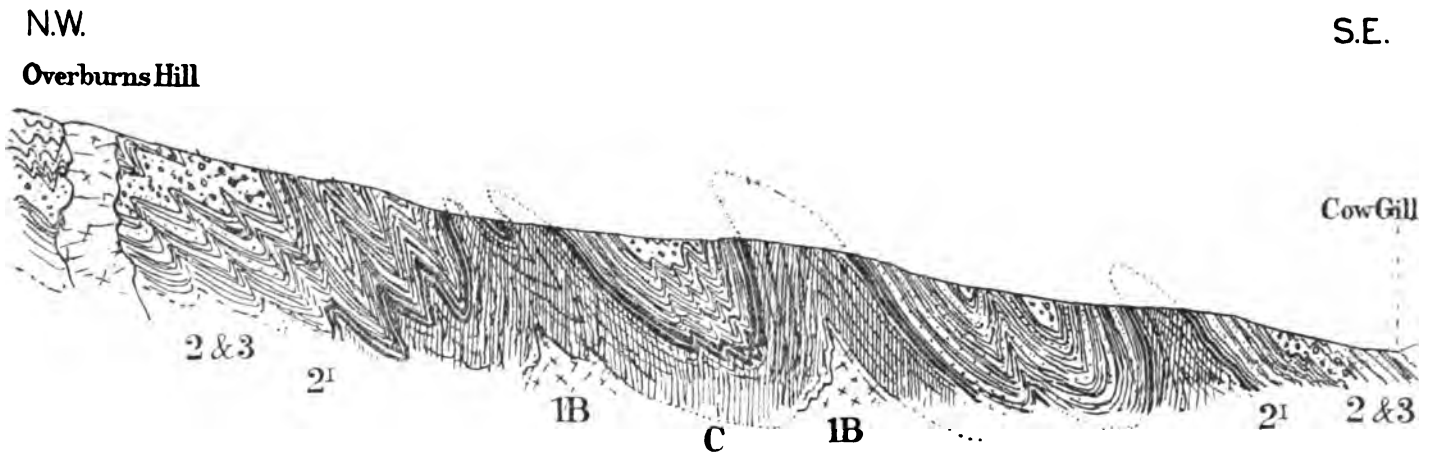


FIG. 53.—Section in Howe Gill, basin of Culter Water, Lanarkshire.

1B. Arenig lavas, &c. 2l. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo-Caradoc). H. "Haggis Rock." F. Camptonite.

two northerly folds, and particularly in the central one, the Glenkiln black shales are well displayed immediately overlying the cherts and mudstones. These are succeeded by grey shales and greywackes, with the band of fossiliferous grit which is laid bare in the stream between the central fold and that to the south.

This section is of further interest, because the crest of the hill displays a fine outcrop of the typical "Haggis Rock," pierced by a mass of camptonite. Attention will be directed to the characteristic features of this conglomerate rock as they are developed north of Snaip. Meanwhile it is sufficient to indicate that though the "Haggis Rock" and its associated strata are inclined to the south-east, and apparently dip below the radiolarian cherts and black shales, it seems to occupy the same position relatively to the radiolarian cherts as the representative of the Kilbucho fossiliferous grit. Indeed, the strata generally throughout the Howe Gill dip towards the south-east, and the axes of the various anticlines are therefore inclined in that direction.

The Wind Gill, which joins the Cow Gill about half a mile west of Birthwood, reveals a similar series of isoclinal folds, with the radiolarian cherts in the centre, followed by the Glenkiln black shales, sandy shales, greywackes, and the Kilbucho conglomerate. The underlying volcanic rocks have not been met with in any of these folds in this portion of the Culter Water basin.

Gair Gill.—In this stream, which flows into the Culter Water about half a mile south of Snaip, an outcrop of black shales has yielded fossils characteristic of the Glenkiln division (Fig. 54). The section is not continuous, but in the light of the evidence already adduced it is possible to assign their relative positions to the various groups of strata. At the head of the stream, where it divides into two small "sikes," the Glenkiln black shales dip at a high angle to the south-east, and have there yielded the following forms:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Didymograptus superstes (Lapw.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Cryptograptus tricornis (Carr.)
Dicellograptus moffatensis (Carr.)
,, *divaricatus* (Hall.)
,, *patulosus* (Lapw.)
,, *sextans* (Hall.)
Diplograptus foliaceus (Murch.)
,, *perexcavatus* (Lapw.)
Acrothele granulata (Linnr.)

An analysis of this list shows it to include certain forms exclusively confined to the Glenkiln division, and others which are common to that division and the lower zones of the Lower Hartfell black shales. The assemblage of fossils proves that here the characteristic fauna of the black shale band still overlies the radiolarian cherts as at Abington. In a sike at the head of Gair Gill this black shale apparently comes to the surface along an isoclinal fold, for towards the north it is rapidly succeeded by grey sandy shales, greywackes, and the fossiliferous grit of Kilbucho. Further down the stream, the rocks are buried underneath boulder clay, but soon the radiolarian cherts reappear repeated in folds.

They are followed at the bend towards the east by an outcrop of the Glenkiln black shales charged with *Dicranograptus zic-zac* and other associated forms. On the hill slope towards the Dimple, occasional exposures of green and red mudstones are succeeded by a fine outcrop of the "Haggis Rock" on the top of the Snaip Hill (Fig. 54).

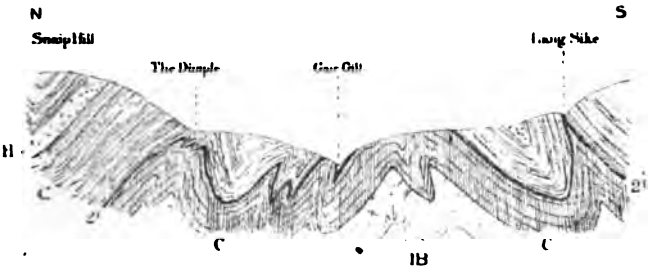


FIG. 54.—Section in Gair Gill, Culter Water, Lanarkshire.

1B. Arenig lavas. C. Radiolarian chert. 2^{l}. Glenkiln Shales. H. "Haggis Rock."

Nisbet Burn.—On the east side of the Culter Water. important evidence is obtained to show the relation of the prolongation of the fossiliferous grit of Kilbucho to the radiolarian cherts and volcanic rocks. In the Nisbet Burn, which joins the Culter Water at Snaip, and also in one of its branches, the Peat Burn, that runs northwards from Tippet Knowe, the lowest visible rocks belong to the volcanic zone. They appear near the foot of the Peat Burn, and consist of diabase-lava, with an outcrop twenty yards in breadth. There they are followed by the radiolarian cherts and by the Glenkiln band of black shales, visible along the line of strike in the Nisbet Burn, where they have yielded traces of graptolites.

The radiolarian cherts come to the surface in two successive anticlines, showing the red and green zones associated with mudstones, one below the junction of Peat Burn and the other at the foot of Hazel Gill—a rivulet that joins Nisbet Burn from the east, about half a mile south of Nisbet Farmhouse. About two hundred yards to the north of Hazel Gill the Glenkiln black shales are seen in the stream, and still further north the fossiliferous grit of Kilbucho appears on the east bank, about four hundred yards to the south of Nisbet Farmhouse. Here the grit has yielded the following among other fragments of fossils: *Leptæna tenuicincta*, *Orthis* sp., and fragments of corals. A reference to the one-inch map (Sheet 24) will show that this outcrop in the Nisbet Burn is quite in the line of strike of the Kilbucho conglomerate to the west of Kilbucho Burn. In the Nisbet Burn, although the strata are isoclinally folded and dip to the south-east at high angles, their order of succession can be established by means of the successive recognisable zones.

The section exposed in the banks of the Culter Water below Snaip and in the adjoining ridge presents one peculiar feature, viz.: the disappearance of the black shale associated with the radiolarian cherts as it approaches the fault that bounds the Lower Old Red Sandstone at Culter (Fig. 55).

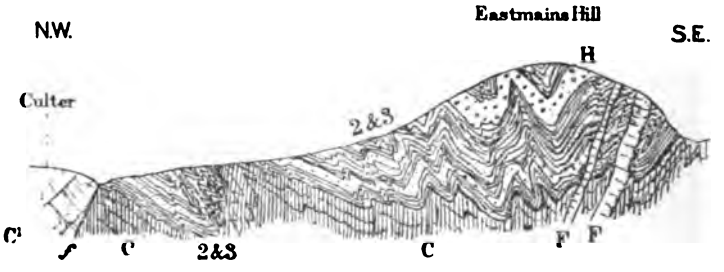


FIG. 55.—Section from Snaip to Culter, Culter Water, Lanarkshire.
C. Radiolarian chert. 2 & 3. Greywacke, mudstone, &c. (Llandeilo-Caradoc). H. "Haggis Rock." Cl. Lower Old Red Sandstone. F. Camptonite dykes. f. Faults.

At the south-east end of the section, the Glenkiln black shales are visible at the foot of the ridge, on the east bank of the stream, beyond the edge of the alluvium. About 200 yards to the south of their line of strike they reappear on another fold, at the road-side south of Snaip Farmhouse, where they are charged with typical Glenkiln fossils similar to those from the Gair Gill already referred to. To the north of the black shales on the east bank of the Culter Water, the radiolarian cherts succeed, here inverted, and apparently overlying the Glenkiln black shales. They are associated with ashy mudstones, which may possibly indicate a continuance of volcanic activity during this stage in the sequence of the zones. Next green shales, mudstones, and greywackes dip steadily towards the north-west. On the top of the ridge (East Mains Hill) a fine exposure of the "Haggis Rock" presents the characteristic features of the bed as exposed on the crest of Lamington Hill. It may be described as a fine conglomerate with a greywacke matrix, in which occur abundant fragments of radiolarian chert representing all the zones of that sub-division of the stratigraphical series. As a rule, these materials form by far the largest part of the ingredients. Further, fragments of volcanic rocks may be observed derived from the series underlying the radiolarian zone, also greywacke and mudstone. Rounded grains of quartz are numerous. The rock has frequently a variegated appearance from the different tints of the chert.

A careful search for fossils has been made in the various exposures of the "Haggis Rock," but the results have not been very satisfactory. Fragments of corals, encrinites, brachiopods, &c., have been found, but never in such a state of preservation as to permit of specific identification.

An important development of soft green mudstones, with ribs and bands of sandy greywacke, from six inches to a foot in thickness, is well exposed in a quarry by the road-side about half a mile south of the fault that bounds the Old Red Sandstone. The strata are there inclined to the north, and thrown into a series of isoclinal folds. There can be no doubt that they underlie the "Haggis Rock" on the crest of the East Mains Hill. The "Haggis Rock" reappears on the hill on the west side of the Culter Water, but is not visible in the stream, which exposes the underlying green mudstones.

The radiolarian cherts are exposed on two anticlines in the Culter Water—one near the Old Red Sandstone fault and the other about 200 yards to the south of that boundary line. They are succeeded directly by the green mudstones without the intervention of the black shales, and dip towards the south-east (Fig. 55). This section is not quite so clear as some of those already described, but there can be little doubt that the cherts exposed on the Culter Water near the bounding fault belong to the horizon above the volcanic rocks, though there the graptolite-bearing shales no longer define their horizon. The green mudstones and shales, which seem to be destitute of fossils, occupy a similar position with reference to the radiolarian cherts as the Tappins group in the valley of the Stinchar, above North Balloch.

Biggar Water District.

To the north-east of the area described in the foregoing paragraphs a fine development of the volcanic rocks and cherts, passing upwards into the fossiliferous conglomerate and grit of Kilbucho, may be studied in the region of the Biggar Water.

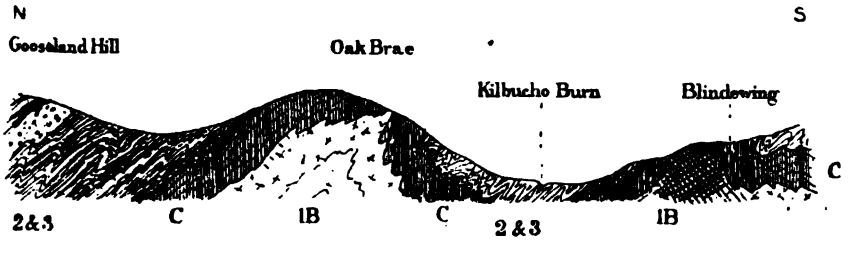


FIG. 56.—Section from Blindewing to Goseland Hill, Kilbucho Burn, Peeblesshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2 & 3. Greywacke and shale (Llandeilo-Caradoc).

To the south-west of Broughton three well-marked anticlines expose the Arenig volcanic rocks. Of these, the most important are those in the valley of the Kilbucho Burn at Blindewing and Oakbrae (Fig. 56). In a small drain about 100 yards west of Blindewing Farmhouse, the diabase-lava can be seen in a much-altered condition. "The felspar occurs in turbid lath-shaped

crystals, penetrating purplish-brown augite. A large portion of the augite is converted into chlorite and serpentinous products. The amygdules are filled with calcite and spherular aggregates of chlorite."

In a quarry, about 500 yards to the south-west of Blindewing, the igneous material has rather the appearance of an intrusive rock. It is there "an ophitic diabase or altered dolerite, composed of turbid plagioclase, augite partly fresh and partly altered, with chlorite, ilmenite, and leucoxene." The flinty mudstones are exposed in the drain near Blindewing Farmhouse on the south side of the diabase-lava; but are concealed on the north side of the fold by a covering of drift.

At Oakbrae, on the north side of the Kilbucho Burn, the south slope of the Goseland Hill supplies another exposure of the diabase-lava in a quarry at the road-side about 400 yards south of Goseland Farmhouse. Here the slaggy character of the rock is well displayed. The lava is bounded on both sides by the radiolarian cherts. On the crest of the anticline at a distance of 300 yards, the volcanic rocks "nose out" and disappear under the cherts, but they come to the surface again about 700 yards to the east, in the form of lava of a more acid character, displaying a ropy surface which has not been denuded. Throughout the felsitic matrix are scattered porphyritic crystals of plagioclase felspar. This rock is traversed by a series of fissures now filled with chert—a feature which seems to point to the conclusion that the igneous material was erupted contemporaneously with the strata among which it lies.

On the north limb of the arch of the volcanic zone at Oakbrae, the radiolarian cherts are repeated by numerous folds, till within a short distance of Goseland Farmhouse the Glenkiln band of black shales succeeds to them, followed in turn by shales and greywackes. On the south limb the black flinty shales also occur on the south side of the cherts, so that in the Kilbucho area the normal succession of deposits overlies the volcanic zone.

About a mile further to the west the Kilbucho conglomerate and associated strata lie in the centre of a series of folds, with the volcanic rocks and cherts underneath. On the Manse Rig the pro-

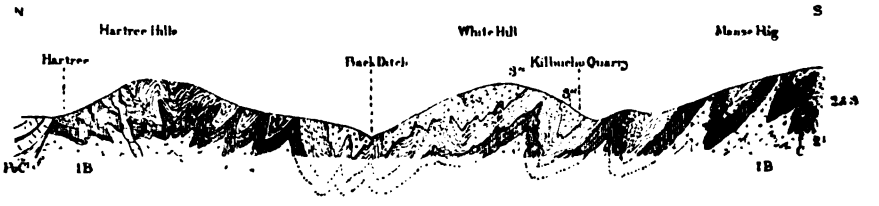


FIG. 57.—Generalised Section from Manse Rig, Kilbucho, to Hartree (near Biggar), Peeblesshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo-Caradoc). 3a. Fossiliferous conglomerate (Caradoc). F. Camptonite dykes. PoCl. Lower Old Red Sandstone volcanic rocks. f. Faults.

longation of the fold with the volcanic rocks at Blindewing, just described, is represented in the radiolarian cherts. Not far to the south the diabase-lavas occur on another fold.

In the burn above the old manse of Kilbucho the rocks are obscured by drift, but on the north side of the stream the fossiliferous conglomerate of Kilbucho is exposed in a quarry about half a mile to the west of the old manse. In lithological character and mode of occurrence it resembles the fossiliferous band at Wallace's Cast, Wandel Water. It has a greywacke matrix, grey in fresh fracture, containing large shale galls or shaly lenticles that give the rock a banded appearance. Further it passes laterally into shales. Limestone nodules occur both in the conglomerate and in the shales. Owing to the decomposition of its carbonates, the rock weathers a rusty brown; the limestone nodules decompose and crumble away into a brown earth. Among the pebbles, the prominent constituent is white vein-quartz in small well-rounded pieces; fragments of radiolarian chert also occur, but in a lesser degree than in the typical "Haggis Rock," and occasionally the Arenig volcanic rocks are represented by minute particles. The fossils occur here in the same way as they do at Wallace's Cast and at Duntercleuch, Leadhills. A comparison of the accompanying list of fossils obtained from the quarry at Kilbucho leaves little room for doubt that the assemblage is identical with that from Wallace's Cast, thus proving the Caradoc age of the beds:

Nidulites favus (Salter.)
Glyptocrinus basalis (M'Coy.)
Encrinite stems.
Stenopora (Favosites) fibrosa (Gold.)
Petraia bina (Lonsd.)
,, *uniserialis* (M'Coy.)
Lindströmia (Petraia) subduplicata (M'Coy.)
,, ,, ,, var. *crenulata* (M'Coy.)
Ptilodictya costellata (M'Coy.)
Leptæna scissa (Salt.)
,, *sericea* (Sow.)
,, *(Christiania) tenuicincta* (M'Coy.)
,, *(Plectambonites) transversalis* (Wahl.)
Orthis crispa (M'Coy.)
,, *calligramma* (Dalm.)
Orthis protensa (Sow.)
,, *rustica* (Sow.)
,, *unguis* (Sow.)
Strophomena kilbuchoensis (Dav.)
,, *(Leptæna) rhomboidalis* (Wilck.)
Modiolopsis orbicularis (Sow.)
Ecculiomphalus sp.
Murchisonia angulata (Sow.)
Platyschisma helicites (Sow.)
Pleurotomaria (Raphistoma) elliptica (His.)
,, ,, *lenticularis* (Sow.)
Orthoceras sp.
Cheirurus clavifrons (Dalm.)
Phacops alifrons (Salt.)
,, *Brongniarti* (Portl.)
Trinucleus sp. (punctate fringe.)

The fossiliferous grits and shales occupy the hill to the north of the quarry, but the radiolarian zone reappears in several folds on the Hartree Hills (Fig. 57). An excellent section may be seen by the road-side crossing the hill in a north-west direction from Goseland Farmhouse, but though the exposures are more or less continuous, the black shales have not been detected there. The cherts seem to pass upwards into red and green mudstones, followed by shales, grits, and the "Haggis Rock" conglomerate.

In the area east of Biggar Water, the first exposure of the

volcanic zone is found on the Pisgah Hill, about two and a half miles west of Broughton (Fig. 58). In the centre of the fold the slaggy diabase-lava (1 B) is met with, overlain on the south side by the red cherts and mudstones (C). In a field to the west of a narrow belt of wood, from an isolated exposure of black shales (2^1), a small but interesting assemblage of fossils has been obtained, viz.: *Diplograptus foliaceus*, *Climacograptus bicornis*, *Dicellograptus moffatensis*, and *Siphonotreta micula*. This list shows that even

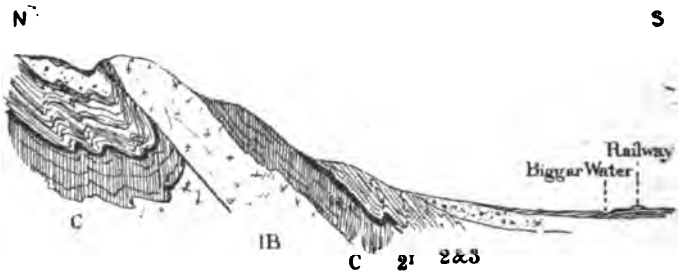


FIG. 58.—Section, Pisgah Hill, Biggar Water, Peeblesshire. (Length, half a mile.)

1 B. Arenig volcanic rocks. C. Radiolarian cherts. 2l. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo-Caradoc).

here certain forms common both to the Glenkiln and Hartfell divisions occur together. And yet the strike of this fold on Pisgah Hill seems to lie rather to the north of the strike of the anticlines in the Culter Water north of Snaip, near the fault bounding the Old Red Sandstone, where the black shales seem to have disappeared. Further evidence of this spasmodic occurrence of the Glenkiln black shales to the north-east of Pisgah Hill will be adduced.

On the north side of the volcanic rocks a fault bringing down the overlying pebbly grits, resembling the fine-grained "Haggis Rock," probably occurs. There is no evidence on that limb of the fold of the existence of the cherts and mudstones. It must be remembered that the rock exposures on this hill are not continuous, and that the diagram has been constructed from isolated exposures.

A remarkable series of outcrops of the radiolarian zone occurs on the ridge that extends from Broughton N.N.W. to Broughton Knowe—a distance of about two miles—which shows the extraordinary reduplication of the strata by means of isoclinal folds (Fig. 59). The dip is towards the south-east, as if there were an ascending series in that direction; but by means of the different stratigraphical zones it is possible to prove that the actual thickness of strata represented in this section cannot exceed a few hundred feet.

There are here twelve anticlines which bring up either the radiolarian cherts as the lowest zone or sometimes even the underlying volcanic rocks. Of these folds, the two most important occur at Broughton Knowe, where, within half a mile of the fault bounding

FIG. 59.—Generalised Section from Broughton to Broughton Knowe, Peeblesshire. (Length, two miles.)

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 2 & 3. Greywacke and shale (Llandeilo-Caradoc). Cl. Lower Old Red Sandstone. f. Fault.

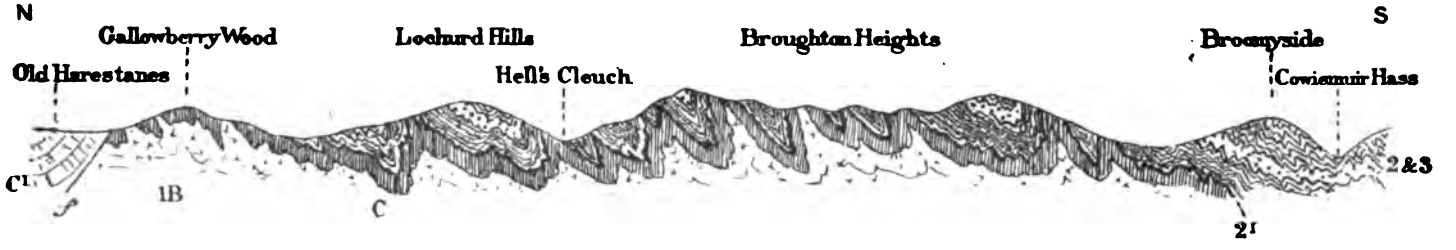


FIG. 60.—Generalised Section across the Broughton Heights from Harestanes, near Castle Craig, to Cowiemuir Hass, Peeblesshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 2 & 3. Greywacke, shale, &c. (Llandeilo-Caradoc).

the Old Red Sandstone, they expose the volcanic rocks in the core of the arch. In the most northerly fold the igneous materials, consisting mainly of amygdaloidal diabase-lavas, can be traced for a mile and a half along the strike. About 200 yards north-east of the farmhouse of Broughton Knowe, at the road-side, coarse volcanic agglomerates occur. To these volcanic ejectamenta succeed the cherts, with red and green mudstones. Round Skirling Craigs, however, the mudstones seem to have in great measure replaced the cherts. About 100 yards to the north-east of the farmhouse of Broughton Knowe debris of black shales is visible on the surface. The volcanic rocks reappear on a second fold about 150 yards to the south of the main arch at Broughton Knowe.

For nearly a mile along the top of the ridge from Broughton Knowe to a point about three-quarters of a mile from Broughton village, there is a constant repetition of the cherts and mudstones, with dark flinty and grey sandy shales. At the edge of the Drove Road, about a mile W.N.W. of Broughton, the black shales have yielded *Cryptograptus tricornis*, *Dicranograptus ramosus*, *Climacograptus*, and *Dicellograptus*. To the north, the radiolarian cherts and black shales pass underneath grey sandy shales and greywackes containing *Diplograptus foliaceus*. A similar occurrence has been noted in the case of the grey sandy shales in Hawkwood Burn, opposite Birnock, which overlie the outcrop of Glenkiln black shales (p. 219). The remaining portion of the section near Broughton is constructed from evidence seen partly in the Drove Road, in quarries, and in the stream near the village.

In the area that borders the Old Red Sandstone between the Broughton and Tarth Burns, similar evidence is obtained of the remarkable reduplication of the strata. Throughout this tract (shown in section in Fig. 60), the strata have a persistent dip to the south-east at high angles. Near the fault bounding the Old Red Sandstone, the diabase-lavas are exposed on several sharp anticlines, followed by the cherts and mudstones, without the intercalation of any black shales above the cherts. Indeed, the black shales have not been detected in the various folds near the Old Red Sandstone rocks between Broughton Burn and Tarth Water. At one locality, about a third of a mile S.S.W. of Old Harestanes, fragments of chert occur in a matrix resembling mudstone, in association with the volcanic rocks. About three-quarters of a mile S.S.E. of Old Harestanes, from an isolated exposure of black shales, *Diplograptus* has been collected.

On the Lochurd Hill, Wether Law, and Pyked Stane Hill, north of Broughton Heights, black shales accompany the cherts. At one locality a graptolite was obtained which resembled *Climacograptus cælatus* (Lapw.). Though the volcanic rocks are not here visible in the line of section, the diabase-lavas occur in mass on the col north of Flint Hill, about a mile to the east, as will be presently shown. Towards the south, the Arenig rocks and black shales pass underneath greywackes and shales.

District stretching from the Basins of the Tarth and Lyne Waters to the Midlothian Coal-field.

Flint Hill to Woolshears Hill, Castlecraig.—A section roughly parallel with that just described extends from the Flint Hill (over 1500 feet) northwards to the Woolshears Hill (1317 feet), south of Castlecraig policies, and overlooking the valley of the Tarth Water. Along this ridge for a distance of about a mile, similar evidence is obtained of the constant repetition by isoclinal folds of the Arenig radiolarian cherts, black shales, and other sediments, with a prevailing dip to the S.S.E. The cherts are visible on eleven separate folds, the best exposure being on the north and north-west face of the Brown Dod (1795 feet), about a quarter of a mile north of Flint Hill, where crags are formed by the cherts which dip S.S.E. at 70°. On the upper surfaces of these cherts the mammilated character of some of the bands is very conspicuous. The grey cherts are in excellent preservation, and in some cases are stained so as to be suitable for microscopic examination of the contained radiolaria. They are also traversed by quartz veins.

An important feature in this section is a fine exposure of Arenig lava in the Ramsgill Crag on the col between the Flint Hill and the Brown Dod. Here a prominent crag, about 50 yards long and 20 feet high, shows the characteristic pillowy structure so typical of the lavas of Ballantrae. The rock is remarkably fresh, vesicular in places, and resembles the fine-grained diabase type. This oval-shaped mass of lava is bounded by bright green turf, and its relations to the surrounding rocks are not visible. But within a few yards from it the cherts appear to the south-west and north-west. A short distance from its south-western termination a very small exposure of black shales occurs on both sides of the cherts, yielding *Dicranograptus minimus*, *Diplograptus foliaceus*, *Cryptograptus tricornis*, and *Climacograptus*. These strata are followed on each side by grits and shales.

Tarth Water.—Advancing now further to the north-east we find in the area that borders the bounding fault between the Tarth and Lyne Waters evidence of the local occurrence of a thin seam of black shale between the volcanic rocks and radiolarian cherts. The igneous materials, consisting of amygdaloidal diabase-lavas, are visible on two anticlines in this district. The more southerly exposure of the volcanic zone is traceable for nearly a mile from the alluvium at Scotston to near Callands Head. Between Scotston and the alluvial flat of the Lyne the breadth of the arch of volcanic rocks is about 200 yards, but at Scotston House it narrows to less than a third of this extent. A few yards to the south of Scotston House the diabase-lava is succeeded northwards by the radiolarian cherts and red and green mudstones; but the strata are inverted and dip towards the south-east. The mudstones are followed northwards by grits and shales exposed to the east of Scotston House. About a quarter of a mile

to the east of Scotston House the diabase comes to the surface along two isoclinal folds, succeeded by the cherts with red and green mudstones. About half a mile north-east of Scotston, pebbly greywackes, with red and green mudstones, probably represent the horizon of the "Haggis Rock." In the area between the Tarth and Lyne Waters, the red and green mudstones are remarkably developed, and show intermediate stages towards the pure radiolarian chert. No black shales have here been observed overlying the cherts.

Tract between the Lyne Water and Lamancha.—From the Lyne Water north-eastwards to Riddenlees, south of Lamancha Station, a distance of four miles—within a belt of ground about a mile in breadth, bordering the Old Red Sandstone and Carboniferous strata—the Arenig volcanic zone comes to the surface along numerous anticlines. In most cases the volcanic rocks are traceable for no great distance—sometimes only for a quarter of a mile, sometimes for a mile. In some of these exposures the slaggy character of the diabase-lava is remarkably apparent. For example, in a quarry on the south-east side of the road from Noblehouse to Grassfield, and about three-quarters of a mile from the former locality, there is an excellent exposure of the lava. Here the rock is very amygdaloidal, and the vesicles are filled with calcite, which decomposes on weathered surfaces. So abundant are these amygdules that the rock resembles a lava of younger Palæozoic age. In all the exposures where a sequence is visible, the diabase-lavas are invariably associated with radiolarian cherts and mudstones passing upwards into red and green mudstones, shales, and greywackes, while in several exposures the black shales are visible, charged with typical Glenkiln forms. In this belt of ground also, as in the region bordering the Old Red Sandstone fault already described, the strata have a persistent dip to the south-east, and hence the folds are isoclinal.

The accompanying section (Fig. 61) shows the relations of the strata in the tract bordering the Midlothian coal-field, about a mile south of Lamancha. It is drawn from a point near Whitemuir in the Carboniferous area, south-eastwards in the direction

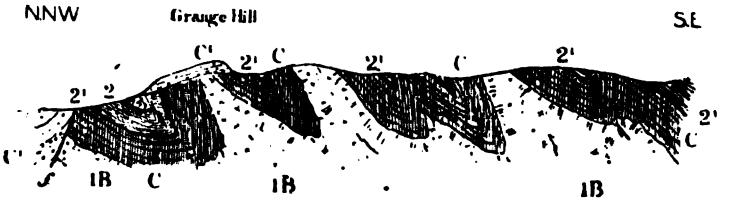


FIG. 61.—Section near Riddenlees, one mile south of Lamancha House, Peeblesshire. (Length, one mile.)

1B. Arenig volcanic rocks. C. Radiolarian cherts. 2. Glenkiln Shales. 2. Mudstone, shale, and conglomerate (Llandeilo). C1. Lower Old Red Sandstone. f. Fault.

of Grassfield. Beginning at the great fault and advancing south-eastwards, the sequence of strata is visible in a small burn flowing towards Whitemuir Farmhouse. Near the fault green shales and mudstones are met with, followed by a pebbly conglomerate representing the "Haggis Rock," which here probably occupies a synclinal fold. Southwards the shales and mudstones reappear, succeeded by the radiolarian cherts and mudstones underlain by a small exposure of diabase-lava.

About 400 yards from the fault, a second fold reveals the volcanic rocks, which are traceable along the strike for nearly a mile. On the south side of this arch the red mudstones and cherts follow in natural order, succeeded by the grey mudstones, when a gap occurs in the section, no rocks being visible until, a short distance to the east, the volcanic rocks appear on a third fold, which is of special interest from the occurrence of a black shale band with Glenkiln graptolites, seen in a small burn about 400 yards S.S.W. of Riddenlees, and about 700 yards north of Grassfield. Here the lava exposed on the north side of the burn is overlain by the cherts and mudstones.

On the same side of the stream a thin seam of blue-black shale, ten to twelve feet thick, occurs apparently in the middle of the cherts, and probably in a synclinal fold. From this seam the following interesting assemblage of fossils has been collected:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Dicranograptus minimus (Lapw.)
,, *formosus* (Hopk.)
,, *ramosus* (Hall.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Diplograptus perexcavatus (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus Schärenbergi (Lapw.)
Dicellograptus patulosus (Lapw.)
,, *sextans* (Hall.)
,, *divaricatus* (Hall.)
Acrothele granulata (Linnr.)
Brachiopod.

An analysis of this list shows that while it contains certain forms that are confined exclusively to the Glenkiln division, it includes also some which pass upwards into the base of the Lower Hartfell black shales.

Further east another interesting exposure of the diabase-lava may be seen in the burn near the Riddenlees Farmhouse. On the north side of the house, by the side of the road leading back to the burn, the black shales are visible in a shattered condition, and apparently in contact with the lava. Here they are probably faulted against the volcanic rocks.

From the evidence now adduced, it is manifest that along the belt of ground extending from Abington by Culter Water and Broughton to where the Silurian rocks come against the Carboniferous formations of the Midlothian basin, the Arenig volcanic rocks, radiolarian cherts, Glenkiln black shales, and overlying sediments are admirably developed and have been laid open on numerous anticlines, which are almost always inverted. By means of the zonal method of interpreting the sections, the extraordinary reduplication of the strata is well shown.

There is one feature, however, to which special attention must be directed, viz., that the axes of the various folds of the Silurian strata between the Broughton Burn and Leadburn, east of Lamancha, are more easterly than the course of the great fault that brings the Carboniferous and Old Red Sandstone strata into conjunction with the Silurian rocks. Hence it follows that the Silurian anticlines are truncated in succession by the great fault, so that as we advance towards the north-east we pass fold after fold of the volcanic series, each in turn being further removed from the Central Moffat region.

Having described the various folds of Arenig lavas and cherts traceable along the margin of the tableland from the Lyne Water to Leadburn, we will now proceed to indicate the occurrence of these rocks with the black shales further south along a parallel belt of ground, three miles in width, between the Lyne Water and Eddleston Station.

Fingland Burn.—The Flemington Burn, which joins the Lyne Water from the east about two miles to the south of Romanno Bridge, receives a tributary named the Fingland Burn, that drains part of the hilly ground north of the Cloich Hills. About a mile and a half up the Fingland Burn a small outcrop of flinty black shales appears, from which the following characteristic assemblage of Glenkiln graptolites has been collected:

Didymograptus superstes (Lapw.)
,, *serratulus* (Hall.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
,, sp.
Diplograptus euglyphus (Lapw.)
Diplograptus foliaceus (Murch.)
,, *perexcavatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
Cœnograptus gracilis (Hall.)

Towards the W.S.W. the debris of this band can be traced in drains for a quarter of a mile, while towards the E.N.E. the strata are buried under boulder clay for a short distance, till on the col at the head of the burn the black shales reappear, but in so crushed a condition that no fossils have been obtained from them. In the Flemington Burn the black shales are succeeded on both sides by olive-green mudstones and thin greywacke bands, resembling the beds on the Tappins Hill in the valley of the Stinchar, Ayrshire. About 200 yards to the north of this black shale band the radiolarian cherts are met with in quarries, much in the same line of strike as the arches of Arenig lavas south of Romanno Mains, previously described. About half a mile to the south of the same band, two folds of radiolarian cherts and black shales are visible in the Fingland Burn at a short distance from each other. The strata in the northern arch are much shattered, black flinty shales being associated with the cherts. They can be traced towards the north-east for a distance of a mile and a half, as far as the slopes of the Wether Law, where, owing to the pitch of the folds, they disappear under greywackes and shales. The southern arch reveals the cherts

without the black shales, the strata visible between the two arches being composed of grits and green shales.

On the west side of the Fingland valley, the cherts and black shales are exposed in three arches on Drum Maw Hill, in the strike of the folds just referred to. Half a mile to the south-west of Drum Maw Hill, the black shale reappears in a small exposure, and has furnished the following fossils:

Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
Cryptograptus tricornis (Carr.)
Dicellograptus Forchhammeri (Gein.)
Dicellograptus moffatensis (Carr.)
,, *sextans* (Hall.)
,, *patulosus* var. *B.* (Lapw.)
Siphonotreta micula (M'Coy.)

In connection with this series of compound folds of the radiolarian cherts and black shales, reference may be made to the occurrence of a band of coarse grit on the slope half a mile S.S.W. of Wether Law, above the cultivated ground at Fingland. It resembles a coarse "Haggis Rock" or pebbly grit, and contains, in addition to the usual fragments of radiolarian chert and volcanic rocks, numerous nodules of blue limestone, varying in size from mere grains to masses two feet in diameter and resembling the conglomerates of Duntercleuch, Kilbucho, and Wrae.

Eddleston and Drochil Castle.—About a mile to the south of the folds of the Moffat series described in the foregoing paragraphs, several compound arches of radiolarian cherts and black shales can be followed at intervals from Eddleston south-westwards to Drochil Castle on the Lyne Water. Some of these exposures of black shales yield a definite assemblage of Hartfell fossils. For example, in the glen at Darn Hall, less than half a mile west of Eddleston Station, on the Peebles branch of the North British Railway, blue-black strains appear in grey shales, which, from the following assemblage of organic remains, evidently represent part of the lower Hartfell black shales:

Diplograptus foliaceus (Murch.)
Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Lasiograptus margaritatus (Lapw.)
Dicellograptus Forchhammeri (Gein.)
Dicranograptus ramosus (Hall.)
Acrotreta Nicholsoni (Dav.)
Siphonotreta micula (M'Coy.)
Acrothele or *Obolella.*

These shales are interbedded with greywackes and shales, the whole series dipping towards the south-east.

Advancing westwards, about a mile and a half west of Eddleston and to the north of the forking of the Fairydean Burn, the observer finds an exposure of radiolarian cherts, which he can also follow along the northern slope and on the crest of Kilrubie Hill, on several anticlines separated by greywackes. On the north-east side of the same hill, black shales are associated with the cherts. By means of debris and rock exposures

one of these folds of Arenig cherts can be traced south-westwards along the ridge from Kilrubie Hill to the head of Harehope Burn and Crailzie Hill. Still further to the west, on Wide Hope Shank Hill, about half a mile south-west of Crailzie Hill, a series of compound folds of the cherts sometimes reveals the black shales. One fold on the northern slope lies close to the outcrop of a band of "Haggis Rock" or pebbly grit; another fold on the southern declivity displays pillowy diabase-lava which, along the north margin of the exposure, appears to be faulted against greywackes. On the further side of a small stream half a mile north-east of Stevenson Hill the diabase-lava may be seen in association with radiolarian chert on the north side of the arch. Here there is a considerable exposure of decomposing vesicular igneous rock, and its outcrop westwards can be traced on the White Rig by the brighter green of the vegetation, indicating the more fertile soil to which this decomposition gives rise.

The radiolarian cherts that appear on the separate folds just described seem to coalesce so as to form a broad compound anticline on the crest of the hill, a mile E.N.E. of Drochil Castle; indeed, the debris of chert is conspicuous on the coomb-like hollow at the head of the valley formed by the burn east of Stevenson Hill. This zone is hidden under the drift which fills that valley, but reappears on the southern slope of the Wood Hill, above the Lyne Water. On this hill, about 100 yards to the north of its summit, an outcrop of decomposing basic lava occurs among debris of cherts and black shales, the radiolarian cherts being traceable westwards to the level of the 900-feet contour line and for some distance eastwards; while a second exposure of the diabase-lava in the hollow between Wood Hill and Wide Hope Shank Hill lies rather to the south of the strike of the fold just alluded to. Again, on the north slope of the wood, at the upper limit of the cultivated ground, another exposure of the volcanic rocks is indicated by their abundant debris, together with fragments of cherts and black shales.

On the Drochil Hills, forming the ridge between the Tarth and Lyne Waters, no fewer than eight anticlines may be observed within a distance of half a mile across the strike, some displaying black shales only, others black shales and radiolarian cherts, while a fourth fold, a few yards to the west of the crest of the ridge, reveals the slaggy pillowy lava.

Eddleston Water, North of Eddleston.—In the district of Eddleston Water, north of Eddleston Station, a few sections show the radiolarian cherts and black shales, one of which (Cowie's Linn Burn) is important, as it furnishes a characteristic assemblage of Glenkiln graptolites in sandy black shales streaked with grey shales.

Cowie's Linn Burn.—This stream, which unites with the Eddleston Water about 2½ miles north of Eddleston Station, traverses the cherts, black shales with Glenkiln fossils, and overlying sediments. About a quarter of a mile up stream from

the railway bridge, greywackes and shales appear, in a crushed condition and dipping in different directions. At a prominent bend in the burn, a few hundred yards further up, several exposures of crushed sandy black shales streaked with grey shales appear, probably on the crests of several anticlines. On the north bank a small part of these shales, not quite so much shattered as the remaining portions, has yielded the following assemblage of Glenkiln graptolites:

Lasiograptus bimucronatus (Nich.)
Climacograptus bicornis (Hall.)
,, *cœlatus* var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus ramosus (Hall.)
,, *formosus* (Hopk.)
Dicellograptus sextans (Hall.)
Cryptograptus tricornis (Carr.)

A small arch of radiolarian cherts a few feet in length may here be traced across the stream. Near these cherts, and in the bed of the burn, the following graptolites were collected from black sandy micaceous shales with grey shales:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)

In the high scar on the north bank, just above where some shattered black shales are pierced by intrusive igneous material, a seam of black shales contains *Climacograptus* and *Dicellograptus*. On the opposite bank, in the cliff bounding the south side of the gorge above the prominent bend, the radiolarian cherts appear in force and form the greater part of the precipice. Further up, greywackes and shales are met with which are thrown into a series of anticlines and synclines, well seen at Cowie's Linn. To the north of the Linn, grey shales, visible on the banks, at the edge of the alluvium of the burn, lithologically resemble the Upper Silurian green and grey shaly mudstones of the Pentlands, Lesmahagow, and Kirkcudbright, and yet from certain rusty-weathering bands characteristic Glenkiln forms were obtained, viz.: *Didymograptus superstes*, *Diplograptus euglyphus*, *D. foliaceus*, and *Climacograptus bicornis*. It appears, therefore, that the horizon of the Glenkiln shales is here represented by ordinary sediment.

Portmore.—About a mile and a half north of Eddleston Station, at the Gala Bank, the radiolarian cherts are displayed in perhaps the finest exposure in the north-west part of Sheet 24 of the Survey Map. About 250 yards east of the Edinburgh and Peebles Road, in a field north of the policies surrounding Portmore House, the cherts appear at intervals for a distance of 200 yards across the strike. They display the red, grey, and green nodular varieties, with radiolaria in abundance. They are best seen on the south side of a small gully, where they form

a rocky cliff, being brought into conjunction with the grey shales on the north side by a fault, with a downthrow to the north. A band of black shales appears on the south bank of the gully, and is there associated with the cherts; it can be followed up the cliff, gradually widening out, until at the top it may be seen lying in a fold of the cherts. From this locality the following forms were obtained: *Diplograptus euglyphus*, *Corynoides calycularis*, *C.* nov. sp., and *Diplograptus foliaceus*.

The north side of the gully is occupied by grey shales and greywackes, which dip south-easterly at 70°, and are traceable eastwards as far as the spring, where they are covered with drift. About 700 yards to the north-east, the cherts reappear in knolls in a field and in a road round the edge of a wood west of Portmore Loch. They are also seen in the wood. On the east margin of Portmore Loch, greywackes and shales rise in the line of strike of the folds of chert to the west. The strata in this region generally dip to the south-east.

CHAPTER XIII.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC FORMATIONS IN THE DISTRICT BETWEEN WRAE, PEEBLESSHIRE, AND THE LAMMERMUIR HILLS.

A BELT of Caradoc strata extending down Tweeddale from Glencotho and Wrae, by Drummelzier and Stobo Castle, to Hamilton Hill and Winkston, north of Peebles (Sheet 24 of the Survey Map), is of special interest, not only on account of the presence of fossiliferous limestone and conglomerate, but also from the occurrence of a remarkable series of interbedded lavas and tuffs, which, as shown in Chapter IV., differ in certain aspects from the earlier volcanic rocks of Arenig time. That these igneous materials were undoubtedly contemporaneous with their associated strata is proved by their relation to the fossiliferous limestones and conglomerates and by the occurrence of fossils in calcareous volcanic tuff. This development of volcanic activity during Caradoc time seems, however, to have been comparatively local, for though the distance between Glencotho and Winkston is only about fifteen miles, the lavas and tuffs have not been traced continuously between these points. Neither have they been found elsewhere throughout the Caradoc strata of the Southern Uplands, save in a few instances in the Sanquhar and Leadhills district.

The fossiliferous limestones, conglomerates, and contemporaneous volcanic rocks are associated with a prominent band of shales and slates, admirably displayed in the Stobo slate quarries. In these excavations a small arch of Hartfell black shales appears and reveals the fossils of *Pleurograptus linearis* zone. The occurrence there of the highest sub-zone of the Hartfell black shales helps to confirm the correlation of the Stobo Slates and Lowther Shales with the Barren Mudstones of the Moffat region. Hence the boundary marking the northern base-line of the Llandovery Rocks in Sheet 24 has been drawn along the southern limit of this belt of strata.

In the following paragraphs, we shall first describe the development of fossiliferous limestones, conglomerates, and contemporaneous volcanic rocks between Wrae and Winkston, and proceed thereafter to indicate their relations to the Stobo slates and Hartfell black shales.

Wrae Quarries.—On the eastern slope of Wrae Hill, overlooking the Tweed, a series of quarries has been opened for different purposes—one for slates, a second for building stone, and

others for limestone. In the eastmost quarry—that opened for building stone—near the Powder Magazine, slates are visible on the north side, and coarse pebbly grit in the centre of the excavation. On the south side, the brecciated material is embedded in the slates, with curious nests of small rounded pebbles of quartz and quartzite, which, owing to the decomposition of the enclosing matrix, can easily be removed by the hammer. In some instances, the pebbles of quartzite reach a considerable size; one in particular, resembling that type of rock in the Perthshire Highlands, measures nine inches across.

At the 1000-feet contour line the lower limestone quarry has been excavated for a distance of 30 yards along, and about 20 yards across, the strike. The higher portion of the quarry is covered with debris, but in the centre an excellent section shows the relations of the lavas and tuffs to the slates, and the presence of fossiliferous limestone in the tuff. Beginning at the north side, we find blue and grey slates protruding through the turf, and close to the north edge of the quarry, dipping to the N.N.W. at high angles. Southwards these slates are succeeded by 18 feet of grey tuff, in which the fossiliferous limestone nodules are embedded. Part of this tuff is coarse, with recognisable fragments of soda-felsite, while other parts are comparatively fine, composed largely of lapilli of soda-felsite lying in a calcareous matrix. A remarkable feature of the rock is the mode of occurrence of its included limestone, in the form of nodules, lenticles, and oval

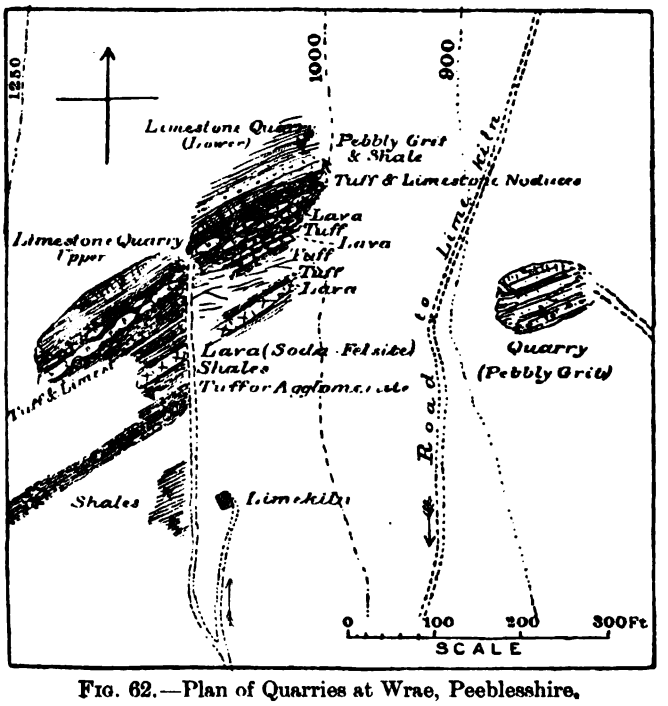


FIG. 62.—Plan of Quarries at Wrae, Peeblesshire.

masses, which are not cleaved. Many of these are fossiliferous; some being abundantly charged with encrinites, others with trilobites, brachiopods, &c. This tuff is succeeded by grey slates with thin intercalations of fine tuff. In the centre of the quarry two bands of fine-grained vesicular lava are separated by a thin parting of grey slate—the bands measuring two feet and four feet thick respectively. They are followed by grey calcareous tuff. Southwards the section is obscured by debris, but at the southern edge cleaved slaggy lava and tuff appear.

The higher limestone quarry is in reality an excavation of the rocks much in the same line of strike as that of the lower; the tuff with limestone bands and nodules occurs on the south side, while the centre and north side are occupied by slates. An important section is displayed by the side of the old roadway leading from the Old Limekiln to this quarry. On the west side of the path grey and blue slates, dipping south-eastwards at high angles, are followed by a bed of fine-grained soda-felsite-lava, forming a prominent rib which extends down the slope into the lower quarry and up the slope in a westerly direction. Under the microscope this rock (No. 7199) shows "phenocrysts of felspar, probably anorthoclase. Groundmass spotted in ordinary light, finely crystalline with small microlites of felspar." By the side of the road this lava-flow is from eight to ten feet thick, but it gradually widens when traced up the slope, and becomes more vesicular. Eastwards, on the farther side of a talus of debris, an exposure of tuff with calcareous nodules is visible also on the south side of the quarry. At this point the following fossils were collected during the visit of the Geological Survey in 1896, viz.: *Lingula attenuata*, *Strophomena grandis*, *Discina perrugata*, *Illœnus Bowmani*, and *Sphærexochus mirus*.

Westwards from the limestone quarries, the volcanic tuff can be traced for a distance of about 300 yards to a point near a stone fence, where it has been excavated for dyke-building. Midway between these localities, a section visible in a small quarry-hole shows cleaved slaggy lava and tuff with slates and breccia containing some volcanic material. Nodules of limestone occur in the tuff, one of which yielded an *Orthoceras*.

The following list of fossils from the limestone and tuff at Wrae and Drummelzier has been collected by the Geological Survey:

Glyptocrinus basalis (M'Coy.)
Crinoid stems.
Asaphus sp.
Cheirurus sp.
Illœnus Bowmani (Salt.)
,, *Davisi*, var. *B. involutus* (Salt.)
Sphærexochus mirus (Beyr.)
Discina perrugata (M'Coy.)
,, sp.
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
Lingula attenuata (Sow.)
,, *longissima* (Pand.)
Orthis actoniæ (Sow.)
,, *calligramma* (Dalm.)
,, *sowerbyana* (Dav.)
Cyclonema sp.
Cyrtoceras scoticum (Blake.)
Orthoceras arcuoliratum (Hall.)
,, sp.

The volcanic zone has not been observed in place west of the stone fence on Mossfennan Brae, but as blocks of tuff occur on the west slope of that hill the rock may not improbably be *in situ* somewhere on that hill.

Glencotho.—About two and a half miles to the south-west of the Wrae Quarries, a similar development of contemporaneous volcanic rocks is associated with the well-known fossiliferous limestone of Glencotho. This locality is situated in the basin of the Holms Water, about half a mile to the south-east of Glencotho Farmhouse, where the Glencotho Burn—an affluent of the Holms Water—receives a small tributary rivulet that drains the western slope of the Benshaw Hill. The volcanic rocks are exposed in this tributary and in quarries on the adjacent slope.

The eastmost quarry affords clear evidence of the association of the limestone with volcanic tuff. At the southern edge of the quarry grey calcareous tuff is seen resting on a tolerably solid mass of limestone, underlain by tuff with limestone nodules, and at the northern limit of the quarry by tuff. The total thickness of beds, which there dip to the S.S.E. at high angles, is 38 feet. Here the tuff contains blocks and lapilli of soda-felsite, embedded in a calcareous matrix. Not far to the south fine-grained lava protrudes through the turf, followed on the south-east side by tuff with limestone lenticles and nodules. The lapilli in the tuff are highly vesicular and are set in a matrix of crystalline calcite.

About 100 yards to the south of the eastmost quarry, an interesting section is visible in the streamlet that drains into the Glencotho Burn. At the south or upper limit of the volcanic series, grits and shales are faulted against a fine-grained lava (soda-felsite) with phenocrysts of felspar in a grey matrix. Northwards this bed of lava is followed by grey shales and greywackes with thin bands of tuff. Again, the westmost quarry supplies an excellent section of calcareous tuff, which can be followed south-westwards along the slope overlooking the Glencotho Burn, where it appears to occupy two separate folds. The following list of fossils has been obtained from the solid limestone and nodules in the tuff:

Crinoid stems.
Glyptocrinus basalis (M'Coy.)
Illænus (young of)
Phacops alifrons (Salt.)
Sphærexochus mirus (Beyr.)
Discina sp.
Lingula attenuata (Sow.)
Leptæna sericea (Sow.)
,, sp.
Orthis actoniæ (Sow.)
,, *biforata* (Schl.)
,, *calligramma* (Dalm.)
Meristella (Whitfieldia) tumida (Dalm.)
Triplesia incerta (Dav.)
Modiolopsis orbicularis (?) (Sow.)
Orthonota undata (?) (Sow.)
Cyclonema (?)
Bellerophon (Euomphalus) sculptus (Sow.)
Holopea concinna (M'Coy.)
Lituites (Trocholites) cornu-arietes (Sow.)
Loxonema sp.
Orthoceras pendens (Blake.)
,, sp.

Drummelzier.—The volcanic zone of Wrae and Glencotho is prolonged to the east side of the valley of the Tweed, where,

south from the Old Castle of Drummelzier, various quarries have been opened in the tuff containing the limestone. In the westmost excavation 45 feet of volcanic ash have been laid open, all more or less highly cleaved. Strange to say, though the volcanic matrix is schistose, the nodules, lenticles, and oval masses of limestone embedded in it are not cleaved. Here, as at Wrae, Glencotho, and Winkston, the limestone yields encrinites in abundance, together with trilobites, brachiopods, &c.

The calcareous tuff is succeeded southwards by shaly greywackes and shales which dip to the S.S.E. About 45 yards to the south of the quarry, a brecciated grit, resembling that in one of the Wrae quarries, appears. By means of various exposures the volcanic ash can be traced along the hill slope to the north-east for a distance of three-quarters of a mile from the westmost quarry.

The tract along which these contemporaneous volcanic rocks have been followed between Glencotho and Drummelzier is about four and a half miles in length. Beyond it to the north-east, for a distance of about seven miles, no trace of them has been observed, save in certain exposures of grit in the Stobo slate quarries, which contain fragmental volcanic material. They reappear, however, on Hamilton Hill to the north of Peebles.

Hamilton Hill, Peebles.—This locality is situated about a mile and a half to the N.N.W. of Peebles on the west side of the Eddleston Valley. A road skirting the hill about the level of the 1000-feet contour line, leads to a slate quarry on the north-east declivity about 200 yards distant from the gateway bounding the cultivated ground. The strata in the centre and on the south side of the quarry consist of grey shales repeated by folds and nearly vertical. On the north side a pebbly grit contains fragments of grey shale, black shale, rounded quartz pebbles, and small nodular masses of limestone. In contact with this pebbly grit, and forming the north bank of the quarry, comes a bed of decomposing lava, vesicular in places, with porphyritic felspars referred by Mr. Teall to the type of the soda-felsites. By means of debris on the slope, this volcanic rock can be traced in an E.N.E. direction to another quarry below a stone fence at the corner of a field, where it forms the face of the quarry for a distance of eleven yards. Here the soda-felsite is highly vesicular, the cavities being filled with carbonate of lime; it also contains porphyritic felspars. On the south side of the quarry, shale debris occurs, and on the north side pebbly grit and shales are found.

About 150 yards further to the west, another small excavation has been opened in a band of grit, containing large fragments of black shale—one over a foot across—from which the following fossils were collected: *Climacograptus bicornis*, *C. cælatus* var. *antiquus*, *C. Schärenbergi*, *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Obolella*.

This part of the hill slope is strewn with fragments of black cherty shales, from which the late Mr. Robert Mathieson obtained specimens of *Diplograptus rugosus* and *Discina*

Portlocki. These fragments may probably indicate the occurrence of an outcrop of black cherty shales in this portion of Hamilton Hill which is concealed by the turf.

In a W.S.W. direction across Hamilton Hill, slaggy lava, likewise of the type of the soda-felsites, occurs apparently on three separate folds. Of these the most important is that seen on the north-west slope just within the cultivated ground and about a mile and a half S.S.E. from Upper Kidston Farmhouse. Here the outcrop of lava, about 20 yards broad, is bounded on the south side by grey shales, striking E. 20° N. and nearly vertical, while on the north side oval masses and fragments of fossiliferous limestone are in contact with and even included in the lava. On the latter side also, pebbly grit with small nodules of limestone occurs close to the soda-felsite. Under the microscope, the volcanic rock, containing angular fragments of white crystalline marble, shows "phenocrysts of an acid plagioclase and probably also sanidine in a ground-mass of microlitic felspars." The calcareous grit, on the north side, is full of fragments of lava, which, under the microscope, are identical with and closely allied to the adjoining rock in the quarry.

Several blocks of limestone were observed in a stone fence bounding this field, and from these blocks the following collection of fossils was chiefly obtained:

Crinoid stems.
Cheirurus bimucronatus (Murch.)
,, *gelasinosus* (Portl.)
Sphærexochus mirus (Beyr.)
Discina perrugata (M'Coy.)
,, sp.
Lingula attenuata (Sow.)
,, *Ramsayi* (Salt.)
Obolella or *Kutorgina*.
Siphonotreta micula (M'Coy.)
Leptæna sericea (Sow.)
Meristella (Whitfieldia) tumida (Dalm.)
Orthis actoniæ (Sow.)
,, *calligramma* (Dalm.)
,, *sowerbyana* (Dav.)
,, *vespertilio* (Sow.)
Orthis sp.
,, like *girvanensis* (Dav.)
Strophomena deltoidea (Conr.)

Winkston.—On the eastern side of the valley of the Eddleston, the well-known fossiliferous conglomerate and calcareous breccia of Winkston occurs about two miles to the north of Peebles. Good exposures, still to be met with in quarries by the road-side and in the road-cutting, show the rock to be variable in character, though in general it may be described as a calcareous breccia, charged with sub-angular fragments of various materials, including grey shale, black shale, quartz, &c., with innumerable small nodules of crystalline limestone arranged in parallel lines. The latter vary in size from pea-shaped masses to nodules from two to six inches across, which frequently decompose and leave cavities, giving the rock a curious pitted appearance. By an increase in the calcareous matter, the rock merges into a tolerably solid mass of limestone, as, for example, in the section at the road-side, a few yards south of an old quarry, where, also, graptolites (including *Climacograptus bicornis* and *Diplograptus*) were found in a fragment of black shale in the calcareous breccia.

In the old quarry the calcareous breccia dips to the S.S.E.

about 60°. Here, after a careful search for fossils during a recent visit of the Geological Survey, the species were obtained that are given in the following list. The smaller limestone nodules consist mainly of a mass of encrinites, the larger blocks yield forms similar to those at Wrae and Glencotho:

Favosites cristatus (Blum.)
Turrilepas sp.
Cheirurus bimucronatus (Murch.)
Illœnus Bowmani (Salt.)
Discina perrugata (M'Coy.)
Lingula attenuata (Sow.)
,, *Ramsayi* (Salt.)
,, sp.
Leptæna (Plectambonites) transversalis (Wahl.)
,, ,, *quinquecostata* (M'Coy.)
Leptæna (Plectambonites) sericea (Sow.)
Meristella (Whitfieldia) tumida (Dalm.)
Orthis actoniæ (Sow.)
,, *vespertilio* (Sow.)
,, *calligramma* (Dalm.)
Siphonotreta micula (M'Coy.)
Strophomena like *shallochensis* (Dav.)
,, *(Rafinesquina) deltoidea* (Conr.)
,, sp.
Triplesia sp.

In an old quarry about 250 yards further to the east an excellent section may be seen of the brecciated grit containing fragments of grey and blue shale, black shale (one fragment yielding *Climacograptus* sp.), chert, greywacke, and various igneous rocks.

Further up the slope, and about 500 yards E.N.E. of Winkston old quarry, the breccia with limestone nodules is well seen. Indeed, it can be traced at intervals, by means of exposures on the slopes and hill-top, as far as Collie Law, where a brown grit with *Orthis* occurs. On the northern slope of Winkston Hill an interesting development of volcanic rocks evidently represents the volcanic zone of Hamilton Hill, Wrae, and Glencotho. They form a narrow band running in an E.N.E. direction from the main road at Winkston Quarry for a distance of about 1200 yards. Their greatest breadth is about 200 yards. Along their northern margin the relations of the volcanic rocks to the surrounding strata are obscured by drift, while on the south side, though the lavas occur close to the sediments, the actual junction has not been detected. The best exposures are to be seen on the north slope of the Winkston Hill, about half a mile E.N.E. of the Winkston Quarry. Here small knobs of pink felsitic lavas appear, one in particular having a red mottled appearance. A microscopic section (No. 7152) of the latter variety is thus described by Mr. Teall: "This is a most beautiful perlitic felsite. All the well-known details of perlitic structure are perfectly illustrated. The perlitic cracks are marked out by ferrite. The most striking feature of this rock is the occurrence of irregular patches of calcite, giving uniform extinction over large areas, in which the perlitic structure is as perfectly shown as it is in the normal felsitic matrix. The main mass of the rock is an extremely fine crystalline aggregate largely composed of very minute felspar microlites. A few of the larger felspar laths occur in the calcite patches."

About 100 yards to the west of the knob composed of the mottled perlitic felsite, pink fine-grained felsite appears in

debris, evidently due to the breaking up of the solid rock underneath. Eastwards at a distance of 250 yards an old quarry near a stone fence furnishes a good section of felsitic lava. To the south of it, fossiliferous crystalline limestone is visible in a small exposure, which, for a distance of 200 yards, can be traced along the southern margin of the felsitic lavas by means of a bright green grassy hollow.

In the stone dykes bounding these fields, large blocks of felsitic lava show beautiful fluxion structure, contortion of the igneous laminæ, and brecciation of the rock. It is highly probable that this structure was produced when the rock was molten and flowing as a viscous mass along the sea floor. Towards the east the felsitic lavas disappear, but south-westwards they can be traced by means of debris on the fields as far as the high road north of Winkston Quarry.

We will now proceed to indicate the relations which the fossiliferous limestone and breccia, with their associated volcanic rocks, between Glencotho and Winkston bear to the Lowther Shales and Stobo Slates, and to the black shale zones of the Moffat series.

Stobo Slate Quarries.—Professor Nicol was the first to call attention to the occurrence of the Wrae limestone in blue slates or shales, which can be traced continuously to the south-west towards the valley of the Clyde and the Lowther Hills, and north-eastwards to Stobo. To the west of Stobo Castle, and on the north side of the valley of the Tweed, the ground is trenched by deep quarries which have been opened along the strike of the beds. The westmost quarry—the largest of the series—exposes a fine section of grey and blue slates with one or two bands of brecciated grit containing fragmental volcanic material, the whole series dipping to the S.S.E. at high angles. In a small quarry immediately to the south, three sharp arches reveal black shales, of which the eastmost outcrop is the most important. These strata consist of alternations of thin black flinty ribs and black shale, much slickensided along movement planes, so that fossils are difficult to obtain. In a prolonged search the following fossils were collected:

Pleurograptus linearis (Carr.)
Dicellograptus Morrisi (Hopk.)
,, *elegans* (Carr.)
,, sp.
Climacograptus bicornis (large forks.)
,, *tubuliferus* (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus margaritatus (Lapw.)
Retiolites (Neurograptus) fibratus (Lapw.)
Diplograptus foliaceus (Murch.)
,, sp.
Dicranograptus sp.

This assemblage indicates the position of the highest sub-zone of the Hartfell black shales of the Moffat region (Lower Caradoc), and hence the Stobo Slates that overlie this band may naturally be regarded as the equivalents of the Barren Mudstones of Moffat (Upper Caradoc).

Holms Waterhead, Glencotho (Sheet 24 of Survey Map).—Various arches of the Moffat Shales appear not far to the

north of the volcanic zone in the Glencotho quarries. In the Hare Burn (which joins the Holms Water at Holms Waterhead), above Holms Waterhead, grits and sandy micaceous shales occupy the water-course as far up as the branching of the stream, where black shales come to the surface. A few feet above the fork, cleaved black shales visible on the bank yielded *Corynoides calycularis*, *Dicellograptus elegans*, *Leptograptus flaccidus*, *Diplograptus foliaceus*. Further up stream radiolarian cherts and black shales are visible on the west bank. The shales being cleaved, fossils are difficult to obtain from them, but *Diplograptus euglyphus* was found in the band next the grey cherts, and *Corynoides calycularis* was collected from the outer zone. Massive grey grits occur on the hill slope not far from the exposure of the black shales at this locality. Near the head of the Hare Burn much cleaved and shattered black chert and shale are met with.

On the south side of the valley, in another small tributary of the Holm Burn further to the south-west, grey cherts and black flints and shales appear near the head of the burn, followed northwards by brown shales and decomposing greywackes with dark blue seams. On the south-western side of the watershed between the Holms Water and one of the branches of the Culter Water, near the Holm Nick (N.W. corner of Sheet 16), a considerable display of radiolarian cherts and black shales may be seen in the Nout Craig, and in the gully formed by the Nout Craig Burn. These strata are here brought into contact with the greywackes by a fault.

Basin of the Eddleston near Winkston.—Similar evidence is obtained near Winkston, indicating that no great thickness of strata can intervene between the outcrops of Arenig cherts and Moffat black shales on the one hand, and the position of the fossiliferous limestone and breccia of Winkston on the other. At the head of a small stream traversing the eastern portion of the Winkston volcanic rocks, and immediately to the south of the lavas, a continuous section of blue shales may be followed for a distance of 250 yards across the strike, and near to this locality debris of Moffat black shales occurs. Again, to the north of Winkston, midway between Old Milkieston and Windylaw, black shales and debris of chert are visible in the fields.

About two miles and a half to the north-east of Winkston evidence has been noted of the existence of folds of the Moffat Shales near the fossiliferous grits. On the slopes of the valley formed by the stream named the Black Cleuch on the six-inch map, that rises between the Cardon Law and Whiteside Edge, three outcrops of the Moffat series may be examined. The two more northerly exposures display the Arenig cherts and black shales, while the most southerly one reveals only debris of black shales. Along the northern declivity of the Whiteside Edge debris of radiolarian chert can be traced for a short distance. The crest of the Whiteside Edge is formed of grits lying between two folds of the Moffat Shales; these merge in places into a breccia charged with angular fragments of shale and cal-

careous nodules with encrinite stems, resembling the fossiliferous calcareous breccia in Winkston Quarry.

Head Waters of the Leithen, East of Eddleston.—In the higher part of the Leithen Water, west of Bowbeat Hill (2049 feet), several folds of the Moffat series display the radiolarian cherts and some of the members of the overlying black shales. The most important series of arches occurs in the Leithen Water, about 2¼ miles due east of Eddleston Station, and also due east of Hog Knowes—a heathery hill rising to a height of 1682 feet on the west side of the Leithen. On the east side of the valley a scar of black shales on the slope of the Bowbeat Rig, from which a small stream flows to the Leithen Water, forms a good base-line for studying the structure of the immediately surrounding ground.

About thirty yards north of the junction of this streamlet, black shales appear in the Leithen Water, and occupy the watercourse for several yards. They are much shattered and veined with quartz and do not yield fossils readily. They are succeeded northwards by brown greywackes and shales which dip south-easterly. At the northern limit of this mass of greywackes and shales a band of pebbly grit exposed in the bed of the stream contains lenticles of black shales, and is followed by black shales associated with black cherty ribs. From these black shales graptolites have been obtained, some of which belong to the middle sub-zone of the Lower Hartfell black shales, including *Diplograptus foliaceus*, *Dicellograptus*, *Corynoides calycularis*, *Climacograptus caudatus*. Fossils are neither abundant nor in good preservation. These black shales are followed northwards by the grey radiolarian cherts, which occupy the bed of the stream for 23 yards, and show the typical features of this zone. Both the nodular and well-banded varieties occur, charged with radiolaria in abundance. North of this outcrop of cherts another exposure of black shales occupies the stream for nine yards, succeeded by cherts for a distance of sixteen yards, and thereafter by black shales associated with black cherty ribs, which pass outwards into sandy black shales and pebbly greywackes with masses of black sandy micaceous shales. These lenticular masses of black shale in the grits yield *Diplograptus foliaceus*, *Corynoides calycularis*, and *Dicellograptus*.

The grits just mentioned extend in the water-course for a distance of twenty-three yards northwards, when black sandy shales reappear, yielding specimens of *Lasiograptus margaritatus*. The grits then once more come to the surface and are followed immediately by another sharp fold of the black sandy shales.

The evidence supplied by this Leithen Water section shows that the beds are repeated by a series of compound folds.

Bowbeat Rig, Leithen Water.—The eastern slope of the Leithen Valley is trenched by a stream that rises high up on Bowbeat Rig, the north-west continuation of Bowbeat Hill, and forms a scar in the upper part of its course. Though no section is visible in the lower part of the stream, important evidence is obtained from the scar in the higher part of the

slope. Here a series of compound folds of the radiolarian cherts and overlying black shales is followed by greywackes and shales. These compound folds are abruptly truncated on the south side by a fault that runs E.N.E. and brings greywackes and shales successively in contact with the cherts and black shales. On the north side of the scar a considerable mass of black shale is repeated by numerous rapid folds. The bands are much decomposed, but at the line of junction with the greywackes the decomposed black shales have furnished the following forms characteristic of the *Pleurograptus linearis* zone: *Pleurograptus linearis*, in great abundance, *Diplograptus quadrimucronatus*, *Leptograptus flaccidus*, *Diplograptus foliaceus*, *Hyalostelia*, &c. It is thus apparent that the highest sub-zone of the Lower Hartfell black shales of the Moffat series is still represented as a black shale in the district of the head-waters of the Leithen.

Leithen Water South of Bowbeat Rig.—About 250 yards south of the junction of the streamlet on Bowbeat Rig with the Leithen Water, two small anticlines of the black shales appear. Fragments of cherts and black shales are found on the north slope of Cardon Law, indicating other exposures in that neighbourhood. The general character of the strata, however, exposed in the Leithen Water resembles that of the Caradoc type in the northern area, consisting of greywackes, pebbly grits, and shales.

An important band of conglomerate is visible in the Leithen Water at a point about a quarter of a mile north-east of the top of Cardon Law, and about half a mile south of the section in the scar on Bowbeat Rig. At one locality on the north bank of the Leithen Water, opposite a sheep-fold, where the best exposure is met with, the conglomerate appears along the back of an arch, which is truncated by a small fault on its northern side. At the broadest part the conglomerate is five feet wide, and consists of a grey grit with pebbles of various rocks and lenticular masses of black chert, the latter sometimes four feet long. Blocks or masses of grey and red radiolarian chert likewise occur, and pieces of black shale containing *Dicellograptus* and *Diplograptus foliaceus*. The rounded pebbles are composed of calcareous greywacke, quartzite (one at least ten inches across), and of quartz-felsite, one nine inches across. The grey shales and mudstones are seen folding over the conglomerate on the face of the bank. Other bands of pebbly grit, not so coarse in texture, occur in the immediate neighbourhood.

This band of coarse conglomerate lies a little to the north of the line of strike of the band of fossiliferous conglomerate on Winkston Hill, believed to be of Caradoc age. It is unfossiliferous, but as the *Pleurograptus linearis* zone (the highest sub-zone of the Hartfell black shales, Lower Caradoc) occurs in black shales not far to the north, on Bowbeat Rig, it may be of Upper Caradoc age. A probable continuation of it is exposed on the hill slope, from 400 to 500 yards to the south-west, near the watershed between the Leithen and Eddleston Waters.

Bowbeat Burn.—This stream rises between the Bowbeat Hill and Bowbeat Rig, and flows south into the Leithen Water. At a point about 300 yards up from the junction of the two streams the radiolarian cherts of Arenig age are exposed on both sides of the valley. On the west side of the valley the black shales and black cherts are seen in contact with the grey radiolarian cherts, the width of the exposure measuring 16 yards. From the black shale bands at this locality, in immediate contact with the cherts, the following forms were obtained: *Didymograptus superstes, Dicellograptus, Diplograptus foliaceus, Climacograptus bicornis.* On the east side of the valley the green mudstones of Arenig age are visible in contact with the cherts, and yield the conodont-like organism which occurs with the Arenig mudstones at Ravengill (Abington).

On the eastern slope of the valley the black shales and cherts make their appearance along the line of strike. Their outcrop can be traced by means of debris to the Leithen Water, near to the point where the coarse conglomerate is visible.

To the south of this band of cherts and black shales two additional exposures of the black shales may be seen on the east slope of Cardon Law; one at the head of a small gully on the north-east face of that hill, the other about 300 yards further to the south at a height of 1750 feet. The more southerly displays alternations of black shales and black cherty bands, from which have been obtained *Diplograptus foliaceus, Climacograptus bicornis, Dicellograptus Morrisi*—evidently belonging to the Lower Hartfell horizon.

Excellent sections of rusty brown Lowther Shales are visible in the streams that drain the col between Cardon Law and Lamb Law, also in the burns forming the sources of the Craighope Burn, east of Bowbeat Hill.

Gladhouse Water (Bowbeat Shepherd's House).—At the south-western end of the Moorfoot Hills, near the ruins of Bowbeat shepherd's cottage, two small burns from east and west join the Gladhouse Water, which flows northward into the South Esk. In the eastern stream the Arenig cherts and black shales for a distance of 800 yards are repeated by folding. At the very head of the scar the width of the exposure of cherts and black shales is 66 yards, the cherts being repeated about fifteen times. The black shales are succeeded on both sides by the grey sandy shales and greywackes. The black shales and black cherts are crushed, shattered, and much veined with quartz; hence fossils are difficult to obtain from them. The following forms were collected from these strata: *Diplograptus foliaceus, Leptograptus flaccidus,* and *Climacograptus bicornis.*

Similar outcrops of cherts and black shales are seen in the small tributary on the west side of the valley. These anticlines lie much in the same line of strike as, and are probably continuous with, the bands of black shale at the head of the Leithen Water, which can be traced across Bowbeat Rig by means of debris underneath the peat.

Black shales and cherts are again visible in two small burns close to the county boundary. In the stream that drains the north slope of the Emly Bank (1980 feet) three isoclinal folds of the Moffat series may be detected, two exposing the cherts and black shales and one merely the black shales. In one of the branches of the burn, draining the northern slope of the Bowbeat Hill (2049 feet), there is a good exposure of the cherts and black shales, much shattered. Excellent sections of the brown shales, which overlie the Glenkiln-Hartfell Shales, also occur in these streams.

Basin of the Heriot Water.

In the various streams which unite to form the Heriot Water (in the north-east corner of Sheet 24) several anticlines reveal representatives of the Moffat Shales, with, in some instances, the radiolarian cherts, accompanied at one locality by vesicular lava. The tributary streams that drain the watershed of the Moorfoot Hills between Mauldslie Hill and Blackhope Scar display numerous folds of the black shale series, which unfortunately, however, yield few fossils, owing to the shattered condition of the strata.

Blackhope Water.—In this stream, at the Blackhope Farmhouse, and for a short distance westwards, grey pebbly grits appear, like the Haggis Rock. Black shales are seen first at a point about 400 yards west from the farmhouse, and in the next 500 yards there are six anticlines of greatly crushed and shattered black shales, from which no fossils have been obtained. Dark and black cherts are associated with these black shales.

On the west side of a small tributary of the Blackhope Water, named the Fernie Syke, three-quarters of a mile south-west of Blackhope Farmhouse, at a point about 150 yards up, an anticline of much shattered black shales, seamed with veins of white quartz, may be seen, from which no fossils have been obtained.

In a small scar (in the line of strike of the outcrop of the cherts and black shales near Bowbeat in the Gladhouse Water), at the head of one of the tributaries of the Blackhope Water, the cherts and black shales are visible.

Hope Burn.—In the higher reaches of this burn a fine exposure of brown micaceous shales with pebbly grits occupies the stream for a long distance. At a point about a mile and a quarter up stream from Garvald Farmhouse a fine development of black shales, much crushed and shattered, affords graptolites in fair preservation. The grey cherts are not visible, but black cherts occur, and thin seams of white clay are intercalated in the black shales. The following forms were here obtained: *Corynoides calycularis*, *Diplograptus foliaceus*, *Climacograptus caudatus* (?), *Climacograptus bicornis*, *Dicellograptus caduceus*, *Dicellograptus* sp. On the south side, where the black shales are brought into contact with the grey and brown shales by means of a fault, the grey shales

bound the black shales on the north (Fig. 63). In this exposure there must be several folds of the black shales.

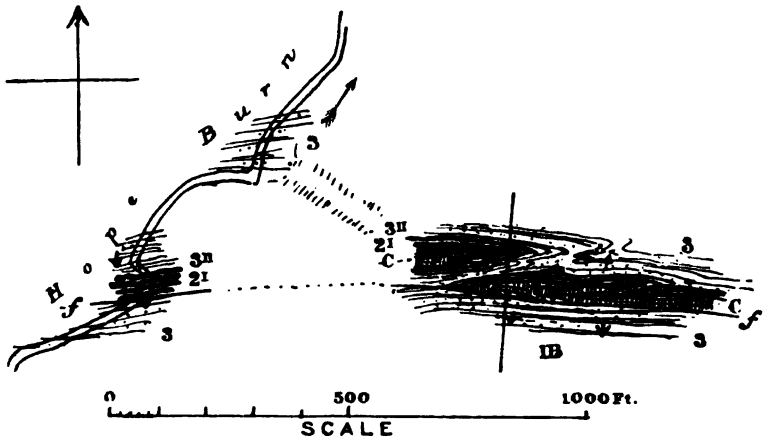


FIG. 63.—Plan of Strata, Hope Burn, Heriot Water.

1B. Arenig lavas. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

Down the stream grey shales appear for a few yards to the north of the band of black shales.

About 100 yards to the E.N.E. of the last exposure of black shales, a gully, which indents the east side of the Hope Burn, and the lower part of which is occupied by a cone of debris, displays an arch of cherts and black shales, followed by decomposing brown-weathering shales and greywackes. A few yards up from this point a very small arch of black shales may be observed with the greywackes folding over them (Fig. 63). From that point upwards, the north wall of the gully is occupied by grey shales and greywackes almost to the head of the scar, while in the bottom of the gully cherts and black shales, too much crushed to yield fossils, are laid bare. Near the head, the gully forks; and just below the

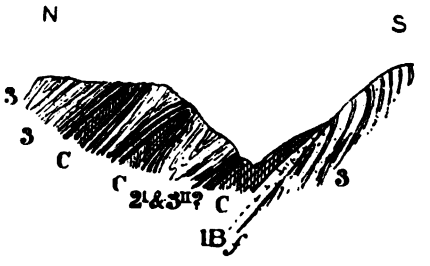


FIG. 64.—Section at Head of Gully, West Slope of Garvald Law, Hope Burn, Heriot Water, along line marked in Fig. 63.

branching a very small exposure of highly vesicular lava, much decomposed, occurs with the cherts. Here both the cherts and the lava are truncated by a fault which runs nearly east and west, with a hade towards the north, and therefore a reversed fault (Figs. 63 and 64). Above the fork, in the main gully, a second small exposure of the vesicular lava is associated with the cherts, and truncated in like manner by the fault. The beds on the south side of the fault consist of brown greywackes and shales (3 in Figs. 63 and 64).

At the road-side between Edinburgh and Innerleithen, on the watershed of the Moorfoots, good section shows the rapid reduplication of the Arenig cherts and overlying sediments, which have a general dip to the south-east at 40°. At the south end, the radiolarian cherts are seen on two compound folds on both sides of the road, the mudstones and shales folding over the cherts. These mudstones, which are violently puckered, contain some of the strains of black shales with fragments of graptolites. They are followed by black shales—from ten inches to a foot thick—with *Diplograptus foliaceus* in abundance, and *Lasiograptus margaritatus*. These shales are in turn succeeded by greywackes and pebbly grits, with lenticular patches and seams of black shale with *Dicellograptus*, followed by dark micaceous and grey shales. The whole section is probably not longer than 100 yards. The radiolarian cherts here present their normal characters, the Glenkiln horizon is represented probably by the mudstones and dark strains, while the overlying black shales and sediments may belong to the Hartfell horizon.

Garvald Farmhouse.—In a small burn which joins the Blackhope Burn due east of Garvald Farmhouse, several folds of the Moffat black shales may be examined. About 200 yards up from the road a scar shows a good exposure of the cherts and overlying black shales, the cherts being associated with brown decomposed shales, containing at one point a thin dark or black seam. On the south side the yellow cherts and mudstones are succeeded by shattery black shales and black cherts, followed by grey shales. On the north side, a black shale band likewise occurs. It is visible in a small exposure, and is followed by grey shales. Further down the stream, the black shales are met with on separate folds overlain by grey shales.

About 200 yards north of the mouth of this burn, the radiolarian cherts are visible, followed by the black shales, and further north by a succession of greywackes and shales; but on the south side of the radiolarian cherts, in the intervening space towards the mouth of the burn, several small exposures of the black shales indicate the rapid reduplication of the strata—a feature which is further illustrated by the puckering of the black shale bands.

Eastwards, in the direction of the mouth of the Crookmill Burn, the black shales may be seen at intervals on different anticlines.

At the northern edge of the alluvium of the Heriot Water north of Little Dod, the radiolarian cherts are visible together with

the black shales. On the farther side of the Carcant Burn, a series of folds reveals the black shales, and in some instances the radiolarian cherts. The most northerly anticline of the black shales is associated with a felstone dyke which has been traced for a considerable distance to the north-east.

Raeshaw Wood, Ladyside.—The sediments which overlie the black shales in this part of the basin of the Heriot Water consist mainly of greenish grey sandy shales, weathering brown and yellow, associated with thin greywacke bands and occasional pebbly grits. The occurrence of these grits is perhaps the most interesting feature of the series. An excellent exposure of them has been laid open in a quarry at the road-side below Raeshaw Wood, on the north side of Heriot Water above the junction of Ladyside Burn. Here they contain numerous pieces of black shale yielding fragments of graptolites, of which the following species were identified during a recent visit to the quarry: *Climacograptus Schärenbergi*, *C. bicornis*, *Cryptograptus tricornis*, *Dicellograptus*, *Didymograptus superstes*. This grit, which points to local elevation and erosion of the cherts and black shales, closely resembles the brecciated grit associated with the fossiliferous limestone of Wrae and Glencotho; it is abundantly charged with small rounded quartz pebbles and occasional chert fragments.

Further down the valley of the Heriot Water, opposite the mouth of Ladyside Burn, the pebbly grit or conglomerate becomes coarser, and contains pebbles of a grey micaceous granitoid rock. In a quarry at the road-side the following graptolites were obtained from fragments of black shale in this bed; *Diplograptus euglyphus*, *Climacograptus Schärenbergi*, *C. bicornis*, *Cryptograptus tricornis*, *Dicellograptus*. A similar band of pebbly grit or fine conglomerate is exposed near the black shales on the Heriot Water opposite the farmhouse of Little Dod.

Gala Water.

Among the head-waters of the Gala, several exposures of the Moffat series may be observed, but few of importance. At the extreme north-west corner of Sheet 25 of the Survey Map, some of these outcrops are recognisable merely by their debris on the surface. They occur on the cultivated ground west of Sandyknowe, and again to the north-east of Hangingshaw, on the crest of Hangingshaw Hill, and near the county boundary at the northern edge of Sheet 25. The black shale debris is sometimes associated with cherts, both zones occurring in the midst of red-crusted greywackes, grits, and greenish shales.

Corsehope.—About a mile and a half to the south of Heriot Station, on the west side of the valley of the Gala Water, and about 250 yards to the south of the Corsehope Burn, red jasper and cherts with radiolaria are well displayed. Grey mudstones are associated with the cherts and jaspers, which yield a doubtful shell,

Not improbably these mudstones may be the equivalents of the shelly mudstones of Arenig age in the Abington district. Debris of flinty black shales met with to the north on the ridge yielded the following fossils: *Diplograptus foliaceus*, *Cryptograptus tricornis*, *Dicellograptus sextans*, *Diplograptus euglyphus*, *Climacograptus Schärenbergi*, *C. bicornis*.

Again, to the east of the valley, on the mossy ground between the Armet Water and the tributaries of the Leader, debris of chert and much crushed and shattered black shales may be found. These local accumulations of detritus doubtless indicate the positions of separate anticlines, for they appear on different lines of strike, and the materials cannot be traced for any distance. The sediments above these black shales consist of grits, greywackes, and shales. Among them one prominent band of conglomerate of special interest has been traced from the county boundary near the Armet Water, by the Clints Farmhouse and Hartside, to a point about half a mile north of Channelkirk, where it passes into Sheet 33 of the Survey Map. This conglomerate runs parallel with another still further south, of a slightly different character. The former is regarded as forming part of the Caradoc formation, while the latter is mapped with the Llandovery series. The lithological characters of this Caradoc conglomerate will be described presently in connection with the exposures of this rock in the quarries at New Channelkirk.

Basin of the Leader Water.

Still further to the north-east, in the basin of the Leader Water, evidence occurs of the existence of the *Pleurograptus linearis* zone in certain outcrops of the Moffat Shales, as previously recorded by Professor Lapworth.

About a mile to the north of New Channelkirk (Sheet 33) the Headshaw Burn is joined by the Windycleuch Burn, which, opposite a bend in the road, exposes thin platy black shales including thin worm-piped barren ribs with black shale partings. From the shales the following fossils were obtained:

Dicellograptus sp.	*Climacograptus bicornis* (Hall.)
Corynoides curtus (Lapw.)	*Diplograptus foliaceus* (Murch.)
,, sp.	*Retiolites* sp.

Above this outcrop the fossiliferous black shales graduate upwards into flaggy shales with dark seams, followed by grits and mudstones all much reddened. Below it a blank occurs in the section, till, at a point 70 yards above the culvert, the grey worm-piped ribs with black shale partings are again laid bare and contain *Diplograptus foliaceus*, *Climacograptus bicornis*, and *Corynoides*.

Headshaw Burn (Head of Lauderdale).—Important evidence is obtained in this stream to show the relation of the Hartfell black shales to the overlying sediments. Above the

point of junction with the Windycleuch, a succession of grits, greywackes, flags, and shales, all much reddened and repeated by folding, may be traced up the stream. Between the foot of the Windycleuch and the foot of the second small tributary of the Headshaw from the north, two arches bring up representatives of the Hartfell beds. The one further down the stream only reveals the higher sandy bands with thin leaf-like dark seams, the other, about 500 yards up from the foot of the Windycleuch, near the junction with a second stream from the north, shows alternations of thin hard flinty ribs with black shale partings. The black seams have yielded *Diplograptus foliaceus* and *Climacograptus*. Further up the stream, jointed grits and shales appear, and at a point 700 yards from the foot of Windycleuch, much crushed black shales seen on the north bank contain *Climacograptus*, *Diplograptus foliaceus*, and *Corynoides*. From this point upwards for a distance of 100 yards in an almost continuous section, grey sandy ribs alternate with black shale seams. At a point about 800 yards from the foot of Windycleuch, the bands occurring on the south side of the stream yield *Pleurograptus linearis*, dip to the south, and display certain distinctive characters, for they here consist of alternations of grey sandy siliceous ribs with black shale partings from an eighth to an inch thick. From these partings the following fossils have been obtained:

Pleurograptus linearis (Carr.)	*Dicellograptus* sp.
Climacograptus bicornis (Hall.)	*Retiolites* sp.
Diplograptus foliaceus (Murch.)	*Corynoides calycularis* (Nich.)

Higher in the valley these beds pass outwards into more sandy bands with dark strains, which are succeeded by stained grits and shales. Where the burn takes a bend to the north, and where a stone fence crosses the stream, the Hartfell Shales are repeated along another arch composed of two minor compound folds, the more northerly of which has afforded the following forms:

Pleurograptus linearis (Carr.)	*Corynoides calycularis* (Nich.)
Diplograptus foliaceus (Murch.)	*Dicellograptus* sp.
Climacograptus bicornis (Hall.)	

Reddened shales intervene between these two folds, while for a further distance of 400 yards up stream an alternation of grits, flags, and shales contains three exposures of the higher bands of the Hartfell black shales, which consist of the sandy bands separated by the dark seams.

In the Headshaw Burn below the foot of Windycleuch, reddened grits and shales dip at high angles and are repeated by folds. At a point about 800 yards down the stream, black shales, much crushed and veined with quartz and carbonate of lime, appear on the west bank, followed on the south side by the grey radiolarian cherts.

On the slope of the hill to the east, black shales with radiolarian cherts in the centre are traceable on the surface by means of debris. Grey shales appear on the south side of this exposure, followed by grit. Southwards, beyond a constant repetition of shales (Lowther type) by folding, the large quarries on the hill slopes E.N.E. of New Channelkirk Farmhouse have been opened along a band of conglomerate and grit. The conglomerate, only a few feet thick, forms a ridge in the quarry, bounded north and south by a coarse grit which has been excavated as building stone for dykes. The conglomerate is somewhat peculiar in character, the matrix being a grit in which small fragments of chert, black shale, grey shale, abundant quartz grains, &c., occur. In fresh fracture the rock has a greenish tint. Perhaps its most notable feature is the occurrence in it of lenticular masses of grey shale, which are bent and folded with the conglomerate, and, so far, have yielded no fossils. The black shale fragments, however, furnish specimens of *Climacograptus caudatus* in excellent preservation, *Diplograptus foliaceus*, *Corynoides*, *Dicellograptus*. The blocks containing these forms must have been derived from the *Climacograptus caudatus* zone. Another piece of black shale, probably from the Glenkiln horizon, was found to contain *Climacograptus cœlatus*, *Diplograptus foliaceus*, *Glossograptus Hincksi*, *Climacograptus Schärenbergi*. Numerous arms of *Dicellograptus* were also found on another slab. Several pebbles have likewise been recorded, one of gabbro and others of fine-grained felsitic rock with porphyritic felspars, the latter being well rounded, and averaging from three to four inches across. On the north side of the quarry, the junction between the shales and the grit is visible. It is obvious that this conglomerate points to local elevation and erosion of the Arenig volcanic rocks, radiolarian chert, black shales, and other sediments. Northwards the beds consist of grey shales or mudstones, containing small flattened nodules of limestone, which differ in character from the limestone of Wrae and Winkston.

Kelphope Burn.—In this stream, which drains the heights near Lammer Law, grey sandy shales are visible at the shepherd's house of Kelphope, and about half a mile further south, coarse pebbly grit is well displayed in the bed of the burn and on the hill slope (Sheet 33). This band is the eastern

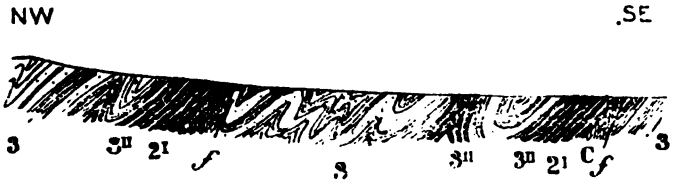


FIG. 65.—Section in a Tributary of Kelphope Burn, Head of Lauderdale.

C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

prolongation of the conglomerate at New Channelkirk; though here not so coarse, its included fragments are similar, and it is embedded in shales.

An interesting section of the Glenkiln black shales may be seen in a tributary of the Kelphope Burn which joins the main stream from the west, about half a mile north from Kelphope shepherd's house. About 600 yards up this tributary, after passing grey shales, the observer encounters a small exposure of flinty black shales on the east bank, from which the following forms have been collected (2^1, Fig. 65):

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Glossograptus Hincksi (Hopk.)
Diplograptus foliaceus (Murch.)
Lasiograptus bimucronatus (Nich.)
Climacograptus bicornis (Hall.)
,, *cælatus* var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)

The specimens of *D. superstes* are especially abundant and well preserved.

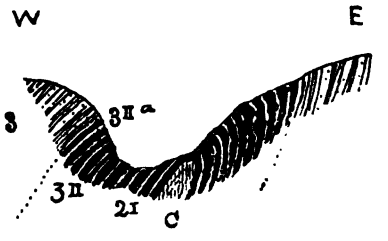


FIG. 66.—Section in Kelphope Burn, 700 yards north of "Friar's Nose," Head of Lauderdale.

C. Radiolarian chert. 2^1. Glenkiln Shales. 3^{II}. Lower Hartfell Shales. 3^{IIa}. *P. linearis*-zone. 3. Greywacke and shale (Caradoc).

A few yards further up the stream, on the same bank, a small exposure of black shales has furnished specimens of *Climacograptus caudatus* in fine preservation, together with *Diplograptus foliaceus* and *Corynoides* in the same seam, belonging to the Lower Hartfell group (3^{II}, Fig. 65).

On the opposite bank, the black shales have afforded *Diplograptus foliaceus*, *Corynoides calycularis*, and fragments of *Climacograptus*. Grey barren shales succeed, which are truncated by a fault, followed by much smashed black shales veined with quartz. About ten yards further up some black shales have yielded:

Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)

These shales are succeeded by grey shales with dark strains, and after a blank in the section, black shales with the grey cherts occur, while in a side rivulet, which joins the Kelphope Burn from the west, the black shales again appear.

Friar's Nose, Lammer-Law Burn.—At the Friar's Nose, where the Kelphope Burn bifurcates, its north-east branch, named Lammer-Law Burn, furnishes evidence of the existence of the *Pleurograptus linearis* zone in the Moffat Shales. Greywackes and shales appear at intervals in the stream as far as a point about 700 yards north from the Friar's Nose (Fig. 66), where a fine exposure of black platy shales runs along the banks of the stream for a distance of upwards of 100 yards. On the north-west bank, and within two or three feet of the grey shales, the following assemblage of fossils characteristic of the highest zones of the Hartfell black shales was obtained:

Leptograptus flaccidus (Hall.)
,, *capillaris* (Carr.)
Diplograptus foliaceus (Murch.)
,, *quadrimucronatus* (Hall.)
Dicellograptus Forchhammeri (Gein.)
Dicellograptus elegans (Carr.)
,, *pumilus* (Lapw.)
,, *Morrisi* (Hopk.)
Neurograptus fibratus (Lapw.)
Pleurograptus linearis (Carr.)
Climacograptus sp.

A peculiar feature of this section is the abundance of *Leptograptidæ* in certain seams close to the grey shales.

On the south-east bank, a few yards further up, *Climacograptus*, *Diplograptus foliaceus*, arms of *Dicellograptus* and *Dicranograptus* have been found.

In a small tributary which drains the Red Scar Rig, black shales appear with grey cherts pierced by a dyke. A few yards above its foot *Climacograptus bicornis* occurs in dark seams in grey shales. Again, the north branch of the Lammer-Law Burn lays bare stained grey flints, and the south branch, black shales and black flints.

Having described the various exposures of the Moffat series which lie to the north of the central Llandovery and Tarannon area, on the southern slopes of the extreme western end of the Lammermuir Hills, we will now proceed to indicate certain outcrops on the northern declivity of that chain.

Lammermuir Hills.

Soutra Hill.—In the Brothershiels Burn, at the south-west margin of Sheet 33, one-inch, and along the crest of Soutra Hill, two bands of dark or black shales are associated with greywackes and shales. About half a mile to the south of these outcrops the Arenig cherts and black shales are again visible near the sources of the Armet Water, in rivulets upwards of 200 yards E.N.E. of Gilston Peel.

Lammer Law (1733 feet).—The radiolarian cherts and black shales rise on two anticlinal folds at the head of the East Burn—a tributary of the Birns Water. In the outcrop on the

east side of the coomb-shaped hollow at the head of this tributary the strata are much shattered and veined with quartz. These Moffat Shales are here associated with decomposing brown, sandy shales of the Lowther type, with occasional bands of grit.

Again, on the scar at the head of the western tributary of the Kidlaw Burn, on the north-west slope of the Lammer Law, black shales appear, with a strike to north and south, and in one instance to N.N.W. and S.S.E. These strata form small arches surrounded by brown decomposing shales. They have as yet furnished no fossils. Some of these black shale outcrops may belong to the same system of folds as those already described in the tributaries of the Kelphope Water, though the beds cannot be traced continuously between the two areas. At least one of the black shale bands on the south slope of the Lammer Law appears to be traceable by means of debris across the moory watershed at the head of the Hope's Water, where the Arenig cherts and black shales appear in a crushed and shattered condition among brown sandy shales, pierced by dykes of acid igneous rock. The chief point of interest in the Hope's Water section is the remarkable system of folding, for although the black shales are exposed at a great height on the slope, they rapidly disappear under brown sandy shales, owing to the pitch of the folds being steeper than the declivity of the ground.

That these sandy shales in all probability represent, in part at least, the Barren Mudstones of the Moffat region is rendered highly probable, if not certain, by the fact that, in the Blinkie Burn—which rises from the north side of Lammer Law—one of the black shale bands has yielded graptolites which elsewhere are associates of *Pleurograptus linearis*. Here, near the source of the stream, in an exposure of black sandy shales overlain by grits and brown sandy shales, the following among other forms were collected: *Diplograptus quadrimucronatus*, *Diplograptus foliaceus*, *Dicellograptus elegans*, *Corynoides calycularis*. From its lithological characters and included fossils, this band is probably identical with the *Pleurograptus linearis* zone of the Friar's Nose.

Further down the same stream, the Moffat series appears twice about half a mile to the S.S.E. of the Castles. The dark flinty bands are the lowest beds visible in the upper exposure, while the Arenig cherts are seen in the lower. The black shales associated with the latter contain *Lasiograptus bimucronatus* and *Climacograptus bicornis*. Here the strata are much reddened owing to the proximity of the Upper Old Red Sandstones and conglomerates. The general dip of all the Silurian strata in this portion of the Lammermuir chain is towards the west or W.N.W., and hence the same beds must be constantly repeated by isoclinal folds.

Papana Water.—Further to the north-east, in that portion of the Lammermuirs drained by the streams south of the village of Garvald, evidence is obtainable of the occurrence of the Arenig cherts and Glenkiln black shales. By far the best

section of these zones is to be found in Papana Water, about two miles south of the village of Garvald (Fig. 67). In this stream, above the point where it is crossed by the fault that brings the Upper Old Red Sandstone in contact with the Silurian rocks, shattered and reddened greywackes and shales extend for a distance of about 100 yards. These are followed by a band of coarse conglomerate which forms a waterfall. This rock contains well-rounded pebbles of greywacke, grey quartzite like that of the Perthshire Highlands, granite, and grey cherts, with fragments of grey and black shale. From the last named, specimens of *Climacograptus* were obtained. Southwards the conglomerate is followed by grey shales, with a band of black shale which contains *Diplograptus foliaceus*. For the next 150 yards there is a constant repetition of black shales, grey shales, and two bands of radiolarian cherts; the beds being much shattered, folded, and traversed by faults. Still further south, grey mud-

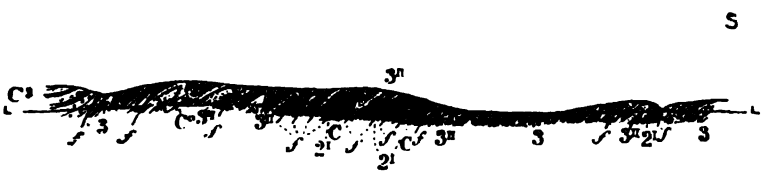


FIG. 67.—Section, Papana Water, two miles south of Garvald.

C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Shale (Caradoc). Co. Conglomerate (Caradoc). C3. Upper Old Red Sandstone. f. Fault.

stones succeed, and are followed by black shales with seams of grey shales, visible in the bed of the stream for a distance of 40 yards. At the southern limit of this broad mass of black shales the radiolarian cherts reappear, truncated on the south side by a reversed fault which brings them in contact with greywackes and shales, and followed on the north side apparently in normal order by black shales, enclosing *Didymograptus superstes*, *Diplograptus foliaceus*, and *Climacograptus*. From another point in the same broad mass of black shales the following typical list of Glenkiln fossils was collected:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
,, *surcularis* (Lapw.)
,, *gracilis* (Hall.)
Thamnograptus typus (Hall.)
,, *scoticus* (Lapw.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
,, *bicornis* (Hall.)
Climacograptus Schärenbergi (Lapw.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Discina Portlocki (Gein.)

It is probable that the Lower Hartfell black shales are also represented in this section, though too much crushed to yield fossils.

For the next 300 yards, beyond an exposure of shattered grits near the black shales, the strata consist of grey and brown sandy shales repeated by constant folds. At a point where the stream divides, black flinty shales occur, from which no fossils were collected owing to their shattered condition. Grey shales of the Lowther type again succeed, and are traceable southwards for a distance of 500 yards. Here grey grits supervene, which are provisionally regarded as marking the northern base line of the Llandovery Rocks, while the grey and brown shales are viewed as the equivalents of the Barren Mudstones of Moffat.

Proceeding eastwards, the observer finds several folds of the Moffat black shales and Arenig cherts in a tributary of the Papana Water about half a mile to the east. One exposure yielded the following Glenkiln assemblage:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
Lasiograptus bimucronatus (Nich.)
Dicranograptus ramosus (Hall.)
Corynoides curtus (Lapw.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Discina Portlocki (Gein.)

Thorter Burn (near Garvald.—This stream furnishes evidence of the easterly prolongations of the folds of the Moffat series. For nearly 600 yards south of the fault between the Upper Old Red Sandstone and the Silurian region, the rocks exposed in the Thorter Burn consist of crushed dark and grey shales and gritty greywackes; the latter being in places conglomeratic. Just above the point where the burn bends at a right angle, flinty black shales occur, too much shattered to yield fossils; these are followed by jointed grits and shales for a distance of 150 yards, where they are in turn succeeded by crushed black flinty shales affording specimens of *Diplograptus foliaceus, Climacograptus bicornis, Cryptograptus tricornis, Dicellograptus.* Next come grey mudstones with dark seams like the Barren Mudstones of the Moffat region; but soon grits appear which dip to the N.N.W. at 37°, and form a series of cascades. These are followed by a development of black shales that occupy the stream for a distance of fifteen yards, and are traversed by numerous dykes of acid igneous rocks. At one point on the east bank, the following fossils occur in thin black shale partings between the black flinty ribs, the graptolites and shells being in fine preservation: *Lasiograptus bimucronatus, D. foliaceus, D. euglyphus, Dicellograptus, Climacograptus bicornis, D. perexcavatus, Corynoides calycularis, Discina Portlocki, Acrotreta Nicholsoni.* These black shales are immediately followed by greywackes, and then by a broad belt of grey sandy shales of the Lowther type, which are admirably exposed on the banks of the stream. The general dip of the strata in the Thorter Burn is towards the N.N.W., so that the strata must here again be isoclinally folded.

Sauchet Water, South of Stenton.—The remaining outcrops of the Moffat Shales on the northern slopes of the Lammermuirs are to be found in tributaries of the Sauchet Water, about a mile and a half south of Stenton. Small exposures of black shales with black flinty ribs appear in two tributaries close to the fault which brings the Upper Old Red Sandstone in contact with the Silurian rocks. One of the outcrops in the main tributary north of Stonypath yields *Diplograptus foliaceus* and *Dicellograptus*; but fossils are difficult to obtain owing to the shattered condition of the rocks. The black shales are here succeeded by grits and greywackes, which are followed southwards by a great development of grey sandy shales. In a little tributary of the Sauchet Burn, about a quarter of a mile south of Deuchrie Farmhouse, a thin dark seam in these grey shales afforded *Diplograptus foliaceus* or *truncatus*, *Dicellograptus complanatus*, and *Climacograptus* sp. This evidence is of importance, as it proves beyond doubt that the grey shales, are the equivalents of the Barren Mudstones of Moffat.

CHAPTER XIV.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC ROCKS IN THE LEADHILLS DISTRICT.

Glengonner Water and its Tributaries.—The belt of ground extending from Leadhills to Crawford and Abington in Clydesdale illustrates in a marked degree the extraordinary reduplication of the Arenig cherts and overlying Glenkiln-Hartfell black shales (Sheet 15 of the Survey Map). This structure is specially developed on the south side of the valley of the Glengonner Water, which falls into the Clyde above Abington. A few of the anticlines near the Leadhills Smelting Mill reveal the underlying volcanic rocks of Arenig age, but the exposures of these rocks become numerous in the Glencaple Burn and adjacent ground, where they form prominent features in the structure of the region.

Two anticlines of volcanic rocks occur to the east of Waterhead, one of which is exposed in a small stream named the Cone Gill, on the hill slope west of the Old Toll Bar at Waterhead. The radiolarian cherts are there followed by the pillowy diabase-lava in the centre of the arch, the cherts reappearing on the north limb of the fold. The south bank presents an excellent illustration of isoclinal folding in the cherts, which are thrown into sharp curves and dip towards the north. Further up stream, the cherts reappear associated with black shales. The following graptolites have been obtained from one of the small exposures to the south of Cone Gill: *Diplograptus tricornis*, *Diplograptus foliaceus*, *Corynoides calycularis*, and *Climacograptus*.

On the moor to the south-west of the Cone Gill, the pillowy diabase-lava is laid bare for a breadth of about 40 yards, associated with the cherts and black shales, debris of the latter being visible by the side of the hill-road leading to Leadhills. Small exposures of the lava may be seen also by the side of the road between the Smelting Mill and the Old Toll Bar at Waterhead. There the lava and cherts are much sheared and rendered schistose.

Bellgill Burn.—This stream, which joins the Glengonner Water from the east not far to the south of the Old Toll Bar at Waterhead, displays a fine section of the Glenkiln-Hartfell black shales, extending up stream for a distance of half a mile. The folds are represented mainly in the black shales; the cherts

appear only on some of them, while in one instance the Arenig lava is visible, about one-third of a mile up from the foot of the stream. In general the black shales are well bedded, and might yield graptolites in fair preservation. At the foot of this stream, at the base of the hill slope on the right bank, a grit seems to be intercalated between the mudstones and flints and the black shales.

On the ridge separating Bellgill Burn from Clow Gill, that flows north-west from Wellgrain Dod to join Glengonner Water, much of the evidence is obscured by a continuous covering of heather; but even on the top of the ridge the cherts and black shales occur. The slope facing the Smelting Mill is marked by some small exposures of Arenig lava cleaved in part; and along the eastern face the cherts and black shales frequently protrude.

The accompanying diagram (Fig. 68), drawn in a north-west direction from the Wellgrain Dod to Brown Neeze along the course of the Clowgill Burn, illustrates the reduplication of the Arenig cherts and the Glenkiln-Hartfell black shales. Only the broader folds are here represented, the strata being highly puckered. On the hill slope east of the burn, and about a quarter of a mile above the foot of the Clowgill Burn, two small arches of the volcanic rocks (diabase-lava) may be observed, which are not visible in the stream. Along this line of section the beds are all much cleaved, so that graptolites are not easily obtained from them. It is further noteworthy that as the folds of Arenig cherts and overlying black shales at the head of Clowgill Burn are followed along the strike into the head-waters of Laggan Gill, they plunge underneath the Caradoc greywackes and shales.

On the eastern slope of the Black Hill a burn which joins the Glengonner Water about a quarter of a mile below the Clowgill Burn gives a continuous section, in the lower part of its course mainly of black shales, and in the upper part, of the cherts and black shales. About 300 yards up from the foot of the stream a band of agglomerate occurs in the cherts, with bombs of lava and blocks of chert in a fine ashy matrix.

In the Glengonner Burn—a tributary of the Glengonner Water—an excellent section of the black shale series is laid open. The isoclinal folds, like those in the Clowgill Burn (Fig. 68), dip to the south-east, save near the foot of the stream. The cherts are well represented, but none of the folds reveals the underlying lavas. About a quarter of a mile up from the foot of the burn, the Hartfell black shales have yielded the following forms:

Climacograptus caudatus (Lapw.)	*Diplograptus foliaceus* (Murch.)
,, *bicornis* (Hall.)	*Cryptograptus tricornis* (Carr.)
,, *tridentatus* (Lapw.)	*Glossograptus Hincksi* (Hopk.)
Dicranograptus ramosus (Hall.)	*Corynoides calycularis* (Nich.)
,, *Nicholsoni* (Hopk.)	

This band of black shale passes downwards (up stream) into black flinty ribbed shales (Glenkiln) with partings of black

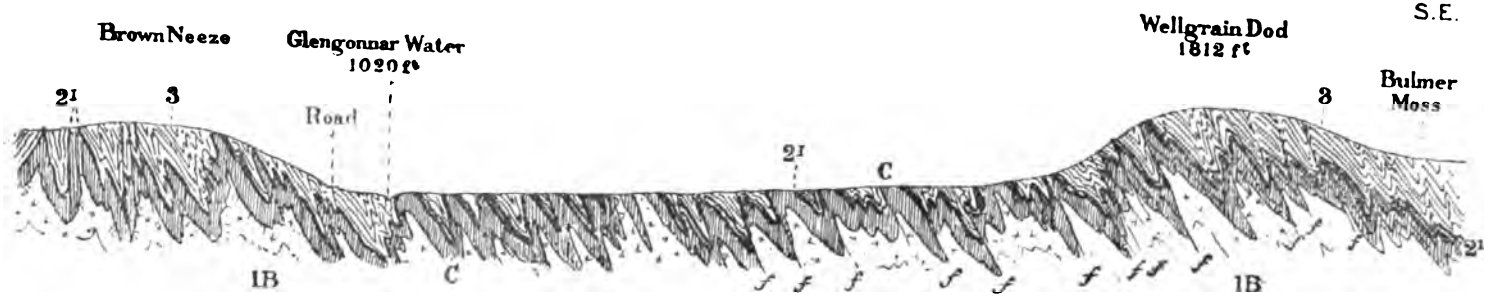


FIG. 68.—Section exposed in the Clowgill Burn, Glengonner Water, Lanarkshire. (Length, a mile and a quarter.)

1B. Arenig volcanic rocks. C. Radiolarian chert. 2 Glenkiln Shales. 3. Caradoc. f. Fault.

shales, succeeded by the cherts, which are faulted against greywackes.

In the Laggan Gill, which rises on the north slope of the Wellgrain Dod and joins the Glengonner Water below Lettershaws, similar evidence is obtained of the extraordinary compression of the strata in this portion of the Leadhills region. In the scars at the sources of the burn some folds reveal the Arenig cherts with the black shales, but the streams cross mainly the greywackes and shales of the overlying series. About three-quarters of a mile down stream from Wellgrain Dod, the folds bring up the diabase-lava much deformed and schostose. The cherts at this point are likewise highly cleaved, and the black shales are much shattered. Below the junction of the Coom Gill, that joins Glengonner Burn about a mile north of Wellgrain Dod, numerous folds of the Arenig cherts and black shales make their appearance. About a quarter of a mile below the foot of the Coom Gill, a section of Hartfell black shales on the south side of a fold of cherts has supplied the following list of graptolites:

Diplograptus foliaceus (Murch.)
Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Dicellograptus Forchhammeri (Gein.)
Dicranograptus ramosus (Hall.)
Glossograptus Hincksi (Hopk.)
Corynoides calycularis (Nich.)

On the north side of this fold *Dicranograptus zic-zac* was found.

The following species were collected by A. Macconochie from the Laggan Gill:

Cœnograptus sp.
Dicranograptus ramosus (Hall.)
,, *formosus* (Hopk.)
Dicellograptus patulosus (Lapw.)
,, *sextans* (Hall.)
,, *moffatensis* (Carr.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
,, like *Schärenbergi* (Lapw.)
,, *caudatus* (Lapw.)
Diplograptus angustifolius (Hall.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)

Much of the stratigraphical evidence in this part of the district is concealed under drift and alluvium in the lower part of the stream, the only rocks visible consisting of greywackes and shales.

Kirk Burn.—This stream, to the east of Laggan Gill, supplies similar evidence of the reduplication of the strata. On the following page a horizontal section is given, drawn along the course of the Kirk Burn. Below it is placed a section drawn along the ridge to the east, which includes Ravengill Dod and Craig Dod.

In the Kirk Burn three folds expose the Arenig lava in tracts varying from fifteen to twenty-five yards in breadth. This section shows the irregular arrangement of the strata, for the beds change the direction of dip within a short distance, the northerly being nearly as frequent as the southerly dips.

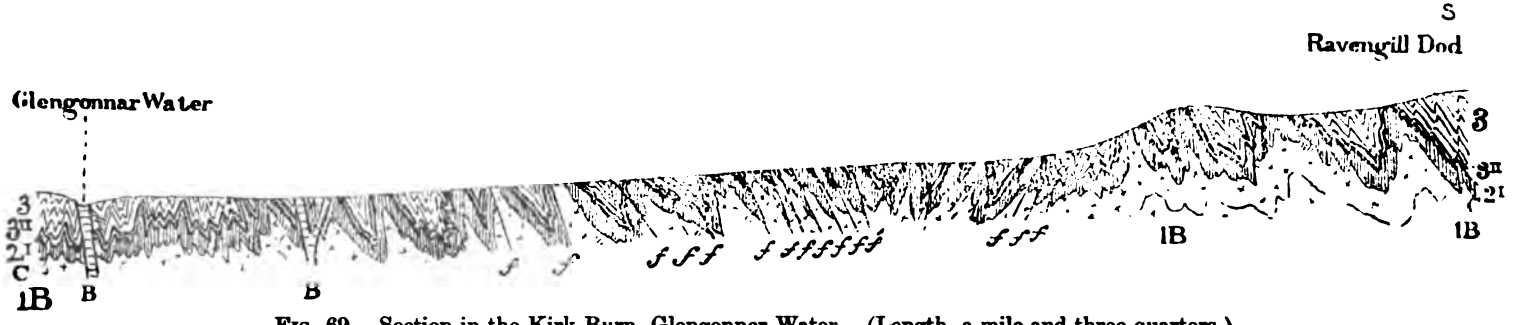


FIG. 69.—Section in the Kirk Burn, Glengonner Water. (Length, a mile and three-quarters.)

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. "Lowther Shale" (Caradoc). B. Dolerite dykes (Tertiary).

FIG. 70.—Section along dividing Ridge between Kirk Gill and Glencaple Burn, Glengonner Water. (Length, one mile and a half.)

1B. Arenig lavas. 1BT. Arenig intrusive diabase. 1. Mudstone (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Lowther Shales (Caradoc). B. Dolerite dykes (Tertiary). f. Fault.

Rather less than a mile from the foot of the stream the following graptolites were got in black shales:

Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *Forchhammeri* (Gein.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Leptograptus flaccidus (Hall.)

Craig Dod Hill.—The Arenig volcanic rocks on this hill are better seen than at any locality to the west. They occur in two folds on the hill-top, about 100 yards distant from each other. In the most northerly fold the breadth of volcanic rock is about 70 yards, the northern boundary line crossing the hill near the Cairn. The mass is composed mainly, if not wholly, of a coarsely crystalline intrusive rock, either an ophitic dolerite or gabbro. As it is bounded on both sides by the radiolarian cherts, there is no evidence of its intrusion being more recent than the radiolarian zone. Northwards towards the Glengonner valley several arches of the cherts and black shales are indicated by small outcrops and debris of black shales.

Another exposure of volcanic rock, about 100 yards further south, forms a prominent rocky knoll about 40 yards broad running in an E.N.E. and W.S.W. direction. The mass consists of diabase-lava, showing the pillowy structure so common in the Ballantrae area. The cherts protrude through the surface on the north limb of this fold, and the black shales are found in a turf-covered hollow, occupying evidently the centre of a synclinal trough between the two prominent arches of the volcanic rocks. There must, however, be compound folds in the radiolarian chert zone between the outcrops of igneous rocks, for along the strike of the cherts a small exposure of lava appears in a tributary of the Kirk Burn, draining the western slope of the Craig Dod.

Southwards, in the direction of the Ravengill Dod, the several anticlines reveal the cherts in the col between the Craig Dod and that hill. Good sections of black shales yielding graptolites are found in two tributaries of the Glencaple Burn, in the strike of the ridge of high ground.

Dry Cleuch.—In the most northerly of these streams, named the Dry Cleuch, which drains the east slope of the Craig Dod Hill, an arch of radiolarian chert may be seen near the head of the scar, associated with black shales, which have yielded the following graptolites:

Dicranograptus zic-zac (Lapw.)
Climacograptus peltifer (Lapw.)
,, *bicornis* (Hall.)
Climacograptus tridentatus (Lapw.)
,, *Schärenbergi* (Lapw.)
Diplograptus foliaceus (Murch.)

Hortin Gill.—About 250 yards further south, the burn named the Hortin Gill, which drains the connecting ridge between Craig Dod and Ravengill Dod, has in the higher part of its course carved a deep rocky ravine out of cherts and black shales. About 200 yards up from the foot of this stream the

cherts appear, followed immediately by black shales, which have yielded the following fossils:

Loganograptus Logani (Hall.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *nitidulus* (Lapw.)
Dicranograptus formosus (Hopk.)
,, *ramosus* (Hall.)
,, *minimus* (Lapw.)
Climacograptus peltifer (Lapw.)
,, *bicornis* (Hall.)
Climacograptus Schärenbergi (Lapw.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *patulosus* (Lapw.)
Cryptograptus tricornis (Carr.)
Corynoides calycularis (Nich.)
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)

This list contains most of the characteristic zonal forms of the Glenkiln group, together with one form, *Loganograptus Logani*, commonly restricted to a lower horizon than the Upper Llandeilo.

This outcrop of the Glenkiln Shales is followed by another of chert. At some distance from the latter, greywackes and shales appear, and in the scars at the very head of the Gill sharp folds of the black shales protrude through the grey shales and greywackes, from which specimens of *Climacograptus caudatus* were obtained (Lower Hartfell).

Raven Gill.—Not far to the south, at the head of another tributary of the Glencaple Burn which rises on the slope of the Ravengill Dod, a series of deep scars on the east slope of the hill, visible from a distance as prominent features, display a section of special interest, owing to the presence of a thin zone of shelly mudstones between the volcanic rocks and the radiolarian cherts. The accompanying ground plan (Fig. 71) and section (Fig. 72) illustrate the relations of the strata. Of three scars or gullies at the head of the Raven Gill, the most southerly, which is the deepest, reveals a fault that brings the volcanic rocks in contact with greywackes and shales (f in Figs. 71 and 72). To the north of this fault, the volcanic rocks are thrown into a series of folds, admirably seen on the slopes of the north scar. The exposures of these rocks include representatives both of the bedded and intrusive series. The bedded type consists of a basic lava highly decomposed, with larger vesicles than usually occur; while the intrusive mass consists of a coarse dolerite or gabbro, well seen on the little dividing ridge between the north and mid scar (1 B *T* in Figs. 71 and 72).

Along the bottom of the middle scar and on the slopes of the north scar, the volcanic rocks are immediately overlain by bands of olive-green flaky mudstones, slightly flinty or siliceous in places, and containing derivative mica, probably muscovite (1 in Figs. 71 and 72). These mudstones resemble to some extent those that surround the nodular cherts with abundant radiolaria. Their distinguishing feature is the occurrence in them of various hingeless brachiopods, all of which have been deep-water organisms, together with *Tetragraptus fruticosus* and *Tetragraptus quadribrachiatus*—graptolites of Middle Arenig age—thereby connecting the underlying volcanic zone with the lavas

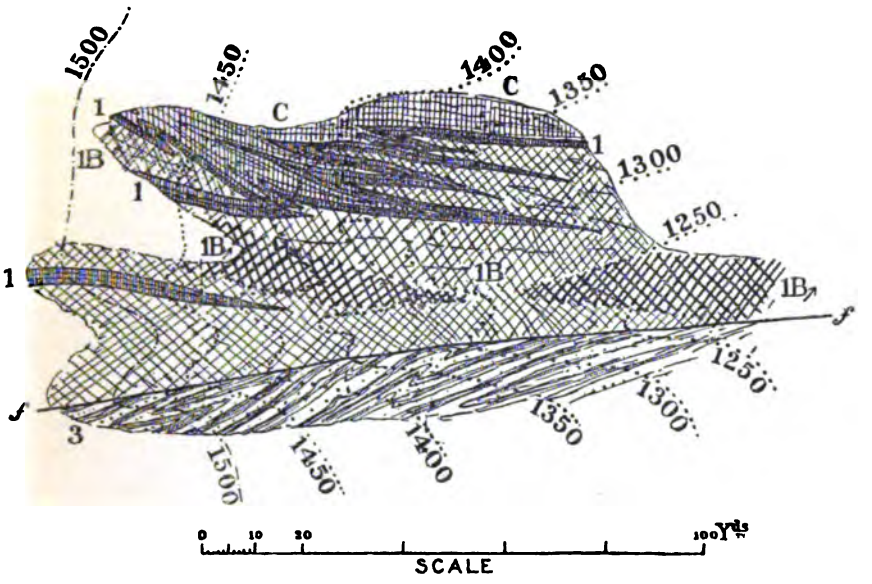


FIG. 71.—Plan of Strata, Head of Raven Gill, Glencaple, Lanarkshire.

1B. Arenig lavas and tuffs. 1B*T*. Intrusive diabase (Arenig). 1. Shelly mudstone Arenig). C. Radiolarian chert. 3. Greywacke and shale (Caradoc). f. Fault. Dotted lines are lines of contour showing the height of the ground in feet.

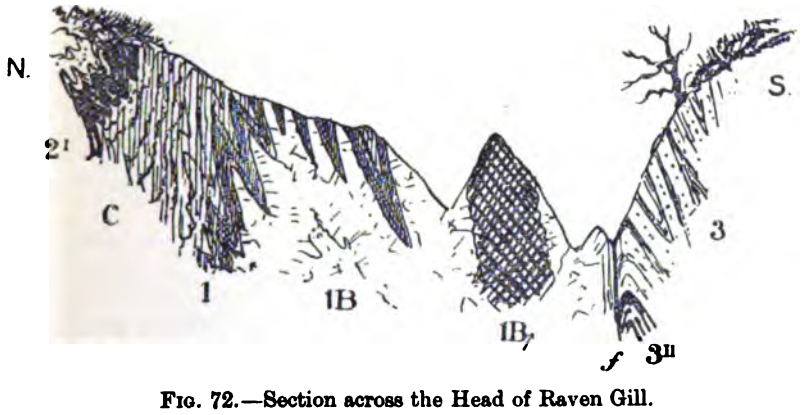


FIG. 72.—Section across the Head of Raven Gill.

1B. Arenig lavas and tuffs. 1B*T*. Intrusive diabase (Arenig). 1. Shelly mudstone (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Fault.

and tuffs of the same age at Ballantrae. The fossils obtained from the Raven Gill mudstones are given in the subjoined list:

Tetragraptus fruticosus (Hall.)
,, *quadribrachiatus* (Hall.)
Caryocaris Wrighti (Salt.)
Acrotreta Nicholsoni (Dav.)
,, sp.
Acrothele granulata (Linnr.)
,, sp.
Lingula sp.
Lingulella lepis (Salt.)
,, *quebecensis* (Bill.)
Lingulella sp.
Linnarsonia sp.
Obolella like *Sabrinæ* (Callow.)
,, *sagittalis* (Salt.)
,, sp.
Kutorgina near *labradorica*.
,, sp.
Discinoid shells.
Annelid jaws (?)
Rods (sponge ?)

The shelly mudstones (1 in Figs. 71 and 72), which are about three feet thick, occupy a synclinal fold on the south side of the northmost scar, and reappear on the north face of the same scar. The shells occur in considerable abundance at both these localities and in fine preservation. The mudstones rest apparently on a bed of fine tuff, which is underlain by the lava. Along the north slope of the northmost scar, they can be followed round the various sharp folds as a thin zone between the overlying cherts and the underlying volcanic rocks. This feature is represented in the ground plan (Fig. 71). Further east only small pockets of the mudstones are visible in the lava, while again the lavas are overlain by the mudstones and cherts on the north limb of the fold.

These mudstones, as already indicated (page 219), have been found at one or two localities east of the Clyde, in the Abington region, where they contain radiolaria.

Glencaple Burn.—In the lower part of the Glencaple Burn, and also on the ridge to the east (Barmy Rig) which overlooks the Clyde, important masses of the Arenig igneous rocks make their appearance. About 200 yards above the foot of the stream greywackes and shales come in contact with coarse gabbro, and are much crushed as if a fault intervened. For a distance of 50 yards the coarse intrusive rock occupies at intervals the bed of the burn. It is succeeded by diabase-lava of a pale grey variety, tuff and green mudstones, with nodules and lenticles of chert, occupying the horizon of the shelly mudstones of Raven Gill. The mass of coarse gabbro is traceable up the north face of Barmy Rig, where it is bounded on the north and south by diabase-lava, which extends down the slope towards the valley of the Clyde.

In the Glencaple Burn the cherts and black shales are met with southwards at intervals, repeated by folds, till an important development of the Arenig volcanic rocks occurs about half a mile up from the foot of the burn. This fold reveals about 40 yards of diabase-lava in the stream, bounded on either side by the cherts. On the hill slope towards the east the breadth of the exposure of volcanic rock is about 200 yards, part of this space being occupied by a trough of cherts. To the south of this outcrop, coarse intrusive rock (dolerite or gabbro) stretches down

the hill slope towards the Glencaple Burn. These intrusive rocks of Arenig age appear again on folds still further south, associated with cherts. This portion of the hill is strewn with rock debris, and at one point a Tertiary dyke traverses the Arenig rocks.

These various folds afford no evidence of the coarse Arenig igneous rocks piercing the cherts or black shales. The intrusion does not reach higher than the lavas.

A small section of black shales with fossils of the Hartfell horizon may be seen on the left bank of the Glencaple Burn, about 300 yards below the foot of Hortin Gill. At the north end, on the bank, the Hartfell black shales are associated with thin grey seams, and thus have a banded appearance of grey and black seams, sometimes a quarter of an inch thick. In these black seams specimens of *Corynoides calycularis*, *Climacograptus caudatus*, and *Diplograptus foliaceus* occur.

Further south the grey seams disappear, and give place to a solid mass of black shales. About eight feet south from the grey seams, the first highly fossiliferous bands yield slabs which are crowded with large specimens of *Corynoides calycularis*. Here may be found in considerable abundance well preserved specimens of *Climacograptus caudatus* and *Diplograptus foliaceus*. In another layer, fine specimens of *Dicranograptus ramosus*, *Corynoides calycularis*, and *Diplograptus foliaceus*, with an occasional example of *Climacograptus caudatus*, have been obtained. The bands near this latter point also yield *Climacograptus bicornis* and *Cryptograptus tricornis*. The relation of this black shale band to other rocks is not visible.

Before concluding this description of the Moffat series, as developed in the Glengonner Water and its tributaries, we must refer to the fact that many of the folds of the black shales lie in the line of strike of the fossiliferous grits and conglomerates of Duntercleuch and the Snar (Caradoc). In the absence of special stratigraphical zones, it is not possible to demonstrate the extensive folding of the grits, but from the manner in which the Caradoc grits anastomose with the underlying radiolarian cherts and Glenkiln-Hartfell shales, it is probable, if not certain, that the upper series is as much folded as the lower.

Clyde above Glengonnerfoot.—At the foot of the Glengonner Water, green and red cherts are visible, and after a blank in the section, reappear in the river Clyde about 200 yards up from Glengonnerfoot. Another blank in the section then occurs for a short distance, but thereafter up to the island in the river, about half a mile from Glengonner, a section may be followed of cherts, black shales, and greywackes, with two outcrops of lava. The rocks are much crushed and disturbed, and hardly ever appear in normal sequence.

The first exposure of the lava lies about 300 yards above Glengonnerfoot. The rock is here brecciated and of the type to be referred to presently as occurring in the hills east of the Clyde. In the black shales south of it, the following graptolites were

found: *Leptograptus flaccidus*, *Dicranograptus ramosus*, *Climacograptus bicornis*, *Diplograptus foliaceus*, and *Acrotreta Nicholsoni*. Two small outcrops of brecciated lava occur about 100 yards to the north of the island. At the island itself there is a great development of black shales.

Wanlock Water and Tributaries.—About two miles up the Wanlock Water from the Spango Bridge at the mouth of the Ree Burn, black shales with radiolarian cherts are traceable at intervals for a distance of about 120 yards. This section is of special interest, because at one point it yields remarkably fine specimens of *Climacograptus bicornis* and of the variety *Climacograptus tridentatus*. Just below the mouth of the Ree Burn, vertical or highly inclined grey and green cherts occupy about 12 yards of the stream section. They present all their typical features, forming hard ribs or nodular bands charged abundantly with radiolaria. On the north side they are succeeded immediately by grey and blue shales, and after a blank in the section by greywackes, grits, and blue shales.

On the south side of the fold, the cherts are followed by grey and blue shales, resembling those on the north side, which occupy the stream for a few feet on the right bank, and are succeeded by greywackes. On the left bank of the Wanlock, opposite the mouth of the Ree Burn, though the beds are there much shattered and fossils are not easily obtained, the following graptolites were collected, belonging partly to the Glenkiln group and partly to the lower portion of the Lower Hartfell black shales.

Cryptograptus tricornis (Hall), in fine preservation.
Cœnograptus surcularis (Hall).
Climacograptus peltifer (Lapw.).
Diplograptus foliaceus (Murch.), in fine preservation.
Dicranograptus Nicholsoni (Hopk.), with a wide angle.
Climacograptus cœlatus, var. *antiquus* (Lapw.), well marked.
Acrothele granulata (Linnr.). This brachiopod is beautifully preserved.

On the further side of some greywackes and shales, the black shales reappear, and yield:

Diplograptus foliaceus (Murch.), in fine preservation.
Cryptograptus tricornis (Carr.)
Corynoides calycularis (Nich.)
Dicellograptus sp..

This assemblage seems to indicate the passage zone between the Glenkiln and Hartfell groups.

Still further up the stream, beyond greywackes and shales, graptolites were found in sooty, shattery black shales, having a characteristic Glenkiln facies, as given in the following list:

Didymograptus superstes (Lapw.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Cœnograptus gracilis (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus Schärenbergi (Lapw.)
,, sp.
Diplograptus foliaceus (Murch.)
Dicellograptus patulosus (Lapw.)

Another fold of black shales may be seen higher up on the left bank of the Wanlock, at a point about 70 yards from the mouth of the Ree Burn. This locality yields remarkably fine specimens of *Climacograptus bicornis* and of *Climacograptus tridentatus*. On the left bank the shales dip to the S.S.E. at an angle of about 80°, are well seen, and can be readily searched for fossils; they occur also on the right bank at the foot of the drift slope. They are flaggy, and break into fine slabs from a quarter to half an inch in thickness. No great variety of fossils is here obtained, but in certain seams specimens of *Climacograptus bicornis* and *C. tridentatus* can be procured in great abundance and in excellent preservation. The following species have been collected here:

Climacograptus bicornis (Hall.), in fine preservation.
,, *tridentatus* (Lapw.)
Dicranograptus ramosus (Hall.)
Dicranograptus Nicholsoni (Hopk.) with a wide angle.
Diplograptus foliaceus (Murch.)
Siphonotreta micula (M'Coy.)

This assemblage shows that the layer from which it was obtained occupies the position of the passage zone between the Glenkiln and Hartfell groups.

A short distance further up, black shales, again seen in the Wanlock, represent probably the Glenkiln band. In the line of strike of this outcrop the radiolarian cherts are visible in the Reedy Gutter, about 50 yards to the south-west of the Wanlock Water. In the last-named stream, occasional exposures are met with still higher up of greywackes and shales, together with a few bands of pebbly grit containing fragments of radiolarian chert.

Glengaber Burn.—In this stream—a tributary of the Wanlock Water—which drains the northern slope of the Glengaber Hill, various outcrops of black shale occur, some of which yield characteristic Glenkiln fossils. The cherts appear in a marked fold about half-way up the stream. One of the best localities for fossils occurs on the hill-road leading to Wanlockhead, where it winds round the slope between the two branches of the Glenaber Burn. At a point on the hill-road between the forks, graptolites occur in good preservation, somewhat decomposed, but abundant. The following list was here obtained:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Dicranograptus ramosus (Hall.)

The form *Dicranograptus ramosus* is most abundant. The Glenkiln black shale is obviously here represented.

On the south-west side of the valley of the Wanlock, the slopes of Duntercleuch Hill are drained by two streams—the Back Burn and the Duntercleuch Burn—flowing into the Wanlock. The sections laid open by these burns are of special importance,

because they exhibit the black shales with characteristic Glenkiln graptolites and the fossiliferous grit and conglomerate of Caradoc age.

Back Burn.—About one-third of a mile above the foot of the Back Burn, where it joins the Glenbuie Burn, black cherts and black shales with fragments of graptolites occur; and about 1300 yards up from the mouth of the Back Burn, black shales, evidently repeated by folds, with grits between, are exposed on the left bank, where they have furnished the following fossils:

Cœnograptus pertenuis (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)

There is no evidence here whether the grits rest unconformably on the black shales. The latter are much smashed and slickensided.

In a scar at the very head of the stream, on the north-east slope of the Well Hill, a fine exposure of the fossiliferous grit (Duntercleuch) may be seen, weathering with a yellowish grey colour. Specimens of a *Theca* were obtained from the grit on this scar; while in the bed of the stream black shales with graptolites are visible.

Duntercleuch Burn.—About 300 yards up this burn from its point of junction with the Wanlock Water, the Glenkiln black shales are well displayed on the north bank. At one point the shales split into fine slabs, and yield graptolites in profusion from certain layers. The following species were obtained from this locality:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *elegans?* (Carr.)
,, *moffatensis* (Carr.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *cælatus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
,, *margaritatus* (Lapw.)
Leptograptus flaccidus (Hall.)
Corymoides calycularis (Nich.)

Greywackes occur on the south side of this outcrop, and also in a fold in the heart of these shales. From the assemblage of forms given in the foregoing list, it is apparent that this black shale band belongs mainly to the Glenkiln group. The occurrence, however, of *Lasiograptus margaritatus* would seem to indicate that the basal portion of the Lower Hartfell black shales is here represented.

Glenmarch Hope Burn.—Near the head of this burn, which is a tributary of the Wanlock Water, on the south-east slope of the Glengaber Hill, besides sections of chert and black shales, both much smashed, a very small exposure of igneous

rock is associated on the north side with cherts and black shales, which resembles some of the igneous rocks of Arenig age.

Sowen Burn (Tributary of the Wanlock at Smelting Mill).—This stream furnishes excellent exposures of radiolarian chert with black shales, but the latter are in many places much shattered and disturbed, so that fossils are not easily obtained from them. Near the foot of the burn, close to the Smelting Mill, the following forms were got from black shales which show a core of radiolarian cherts in the centre of the fold: *Cœnograptus pertenuis, Dicranograptus zic-zac, Dicranograptus ramosus, Climacograptus bicornis, Diplograptus euglyphus, D. foliaceus, Leptograptus flaccidus, Dicellograptus sextans, D. Forchhammeri, Cryptograptus tricornis.* One of the marked features of the Sowen Dod (1783 feet) is the abundance of chert debris along the line of outcrop occurring close to each other. The hard chert ribs are very conspicuous along the hill-top near the county boundary.

Snar Water, Wanlockhead.—Round the head-waters of the Snar, although the hills have a more or less continuous covering of heather, repeated folds of the Arenig cherts and black shales are nevertheless indicated by debris on the surface exposures in scars or burns on the hill slopes. Along the eastern slope of Sowen Dod and Snarhead Hill there are about twenty separate folds of the Arenig cherts and black shales. Sometimes only the black shales come to the surface along sharp plications, but as a rule the cherts form the prominent feature of the folds. It is important to note, however, that along the strike of these folds, on the ridge forming the watershed between the head-waters of the Snar and Leadhills, the strata consist of grits, greywackes, and shales. The Arenig cherts and the Glenkiln-Hartfell black shales gradually "nose out," and the folds are continued in higher beds.

On the east side of the Snar Water valley, in a scar draining the south slope of Hunt Law, a broad exposure has been laid open of the Arenig cherts and black shales. Here the observer may see the features which these rocks present over a considerable area of the region north of Leadhills. The black shales are bleached white or grey, and their graptolites are in such a very poor state of preservation as to be of little service for zonal classification. Further, the cherts frequently decompose into a white clayey material. To such an extent is this the case in the Leadhills region that probably some felspathic constituents may enter into the composition of the radiolarian cherts.

About 200 yards south from the foot of the scar just referred to, at the side of the path leading to Leadhills, a very small projection of the diabase-lava in the chert forms the only outcrop of the volcanic zone in the head-waters of the Snar.

For a mile below its source, the Snar Water flows through an alluvial flat, in which no solid rock is visible. Within half a mile of the Snarhead shepherd's house, gritty greywackes and shales appear in the stream, and a little lower a well-marked

band of grit may be seen, resembling the fossiliferous grit of Duntercleuch. About 70 yards north of this outcrop the cherts appear with the black shales. Further down stream (300 yards north of Snarhead) an arch of the cherts with black shales is laid bare in the water-course. In the core of this fold, on the right side of the valley, coarse dolerite or gabbro appears, which is traceable for a short distance. The cherts, however, can be followed eastwards to the crest of the ridge between the Glenkip Burn and Snar Water.

About 60 yards south of the junction of the Reecleuch Burn with the Snar Water, an important section exposes the volcanic rocks. Greywackes in the bed of the stream are followed by pillowy lava, which is visible in an adjoining rocky knoll. The volcanic zone is succeeded southwards by an outcrop of black shales seen in the Snar, and still further south by the radiolarian cherts. A small exposure of radiolarian chert may be seen in the burn on the north side of the mass of lava, so that the latter might occur on a separate fold from that of the cherts south of the black shales. The cherts occur along this strike to the west of the Reecleuch Burn.

These folds of volcanic rocks, Arenig cherts, and black shales in the Snar Water lie much in the same line of strike as the outcrops of the Reecleuch Hill to the W.S.W.

The fossiliferous breccia or conglomerate is well displayed in the Snar, not far below the shepherd's house. It occurs also further down the valley on the slope of Snar Law, and in the Slough Burn on the west side of the valley.

Glenkip Burn (Tributary of the Snar Water).—At the head-waters of this stream great scars display fine sections of the Arenig cherts highly decomposed, and of the black shales, usually bleached to a white or grey tint. The same difficulty is here presented of obtaining fossils for zonal classification. The evidence of rapid reduplication of the strata by folding is abundant, though in this valley denudation has not proceeded far enough to reveal the volcanic rocks.

From an exposure of black shales, about one-third of a mile down this stream, the following fossils were got:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus euglyphus (Lapw.)
Climacograptus sp.

The belt of rapidly folded cherts and black shales at the head of Glenkip Burn is upwards of half a mile broad; northwards to the point of junction with the Snar Water—a distance of about a mile and a half—the valley traverses a succession of pebbly grits or conglomerates, greywackes, and shales of Bala age. The dips in opposite directions show that the strata are repeated by folds; but it is clear that many of the folds are isoclinal. Here, as has been already remarked with regard to other parts of the region, there may be quite as much reduplication of the over-

lying sediments of Bala age as of the Arenig cherts and Glenkiln-Hartfell black shales.

The folds of cherts and black shales so conspicuous at the head of the Glenkip Burn are traceable in many cases across the ridge in the direction of Glengonner Water. Eastwards, however, they "nose out," and plunge underneath overlying sediments.

Glendorch Burn.—This stream rises on the slope of the Waterhead Hill north of Leadhills, and joins the Snar at the Old Castle of Snar, about a mile and a half south from Duneaton Water. Near its head several folds of black shales and cherts occur; but northwards to near the foot of Sim's Burn greywackes, pebbly grits or fine conglomerates, and shales or mudstones are exposed. The pebbly bands yield the Duntercleuch series of fossils. There can be no doubt that they are repeated again and again by sharp folds.

From Glendorch shepherd's house to near the foot of the stream, grey flags and mudstones, with occasional bands of grit, dip generally to the S.S.E. at about 70°. About 200 yards above the foot, an outcrop of black shales has supplied the following fossils:

Diplograptus foliaceus (Murch.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
,, *caudatus* (Lapw.)
Dicranograptus ramosus (Hall.)
Dicellograptus moffatensis (Carr.)
Glossograptus Hincksi (Hopk.)
Lasiograptus margaritatus (Lapw.)
Cryptograptus tricornis (Carr.)
Acrotreta Nicholsoni (Dav.)
Corynoides calycularis (Nich.)

This assemblage of fossils proves that this shale must belong to the Lower Hartfell horizon. Though the radiolarian cherts are not here visible in the Glendorch Burn, there can be little doubt that the black shales appear along the crest of a sharp fold. The occurrence of this band is of importance, because it helps to fix the age of the brown shales and fossiliferous grits, so well developed in the Glendorch valley.

Cog Burn and its Tributaries (West from Wanlockhead).—The lower reaches of this stream, below the point of junction with the Glensalloch Burn, afford few exposures of solid rock. The Cog Burn, in that part of its course, winds through alluvial deposits flanked by high banks of boulder clay. From the mouth of the Glensalloch Burn upwards to the foot of the Glendorch Burn—a distance of about three-quarters of a mile—very massive greywackes and grits with blue and grey shales form the section.

At the mouth of the Glendorch Burn, an important section, on the right bank of the stream, shows the sequence from the radiolarian cherts to the Glenkiln black shales, followed by a remarkable breccia at the base of the overlying arenaceous series. At the bend of the stream, cherts with radiolaria occupy about 25 yards of the section, preserve their nodular character, and are there seen to be repeated by sharp folds. On the south side they are followed by a thin seam of shales, succeeded by a bed of

breccia about 14 feet thick, composed of angular fragments of grey and dark chert with radiolaria. On weathered surfaces the brecciated character of the rock is very conspicuous, as the included fragments weather with a whitish colour, while the matrix of the rock is grey. This bed of breccia, which probably indicates a local unconformability, is succeeded by a band of black shales, measuring about 24 feet across, which are much jointed, and yield graptolites sparingly and in poor preservation. The following among other forms were here obtained: *Cryptograptus tricornis, Dicranograptus ramosus, Lasiograptus bimucronatus, Climacograptus*, &c. These black shales contain dark siliceous ribs like those of the Glenkiln black shales group; and though the typical Glenkiln assemblage of graptolites has not here been met with, it is evident from the character of the beds and the occurrence in them of *L. bimucronatus* that they belong to that division. They are followed by a bed of grit (six feet thick) containing angular fragments of radiolarian chert and a few pieces of black shale. Further south, dark grey greywackes and shales are visible on the base of the slope and in the stream. On the north side of the anticline, greywackes and dark shales come in conjunction with the radiolarian cherts.

It is interesting to observe that a section showing a sequence from radiolarian cherts to Glenkiln black shales and overlying breccia is visible in a small tributary of the Glensalloch Burn, about half a mile to the E.N.E. of the locality just referred to. The streamlet is not marked even on the six-inch map, but it drains the northern slope of the Lowmill Knowe. About 80 yards above its junction with the Glensalloch Burn—no rock being visible in this space—the first exposure is met with on the east bank, consisting of grey, green, and dark cherts full of radiolaria. Only about three feet of cherts are seen. These are followed on the south side by three feet of decomposing black shales, weathering grey and rusty brown. About three inches of this band yield graptolites in fairly good preservation. The following forms were here found:

Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
,, *tridentatus* (Lapw.)
,, *Schärenbergi* (Lapw.)

This fossiliferous band is succeeded further south by about 12 feet of grit which passes in places into a fine breccia, with a gritty matrix, containing angular fragments of radiolarian chert of the same colour as the chert-band close by. The derived fragments are small, but one was found that measured four inches across. The breccia passes upwards into grits with minute chert fragments and brown shales. These beds are nearly vertical, or dip to the south-east at about 80°. A short distance up the streamlet another band of brecciated conglomerate is seen, containing fairly large fragments of radiolarian cherts. This anticline, of which only one limb is visible, cannot be traced

continuously to the Cog Burn, but it is much in the same line of strike as the arch at the foot of Glendorch Burn. The latter streamlet lays open numerous folds of the radiolarian chert with small exposures of black shales, the higher portion of its course being occupied by blue clayey shales with sandy ribs. About 400 yards up the stream, one of the synclinal folds includes another band of brecciated grit with chert fragments.

Before describing the black shale bands in the basin of the Cog Burn above Cogshead, we may refer to the series of brown-weathering greywackes and shales in the Glensalloch Burn, which resemble in certain points the so-called "Margie series" of greywackes and shales in Forfarshire and Kincardineshire. In fresh fracture the rocks are grey and blue.

In the higher reaches of the Cog Burn and its tributaries above Cogshead, sections of black shales yield at some localities well-preserved graptolites. At the Craigy Cleuch—a tributary of the Cog Burn due south of the shepherd's house at Cogshead—dark blue shales appear at the foot of the stream, which have not yielded graptolites. At the head of this burn two small branches have cut deep scars in the Silurian rocks. In the westmost branch, on the brow of the hill, grey shales and mudstones with dark shales contain *Diplograptus foliaceus* and *Dicranograptus*. In the eastmost branch, similar beds are visible. Just above the fork of this branch, shattery black shales have yielded *Cryptograptus tricornis*, *Diplograptus foliaceus*, *Acrothele granulata*, *Acrotreta Nicholsoni*, the brachiopods being well preserved. A few feet from the fork, the following forms were obtained in a seam of black shale:

Dicranograptus zic-zac (Lapw.)
Diplograptus euglyphus (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Dicranograptus Nicholsoni (Lapw.) (with the wide angle).
Dicellograptus sp.
Climacograptus Schärenbergi (Lapw.)

Howcan Burn (Tributary of the Cog Burn).—About 300 yards to the east of Cogshead the Howcan Burn joins the Cog Burn from the south-east, and near the Martyrs' Knowe a small exposure of black shales, dark blue and flaggy, have yielded *Cryptograptus tricornis*, *Dicranograptus ramosus*, *D. Nicholsoni* (with the wide angle), *Climacograptus*, and *Acrotreta Nicholsoni*. Further down this tributary there is a better exposure of black shales of a similar type yielding *Dicellograptus sextans*, *D. elegans*, *D. Forchhammeri*, *Cryptograptus tricornis*, *Climacograptus bicornis*.

On the north side of the valley, the Cog Burn receives a tributary—the Glenlosk Burn—a mile east of Cogshead, which reveals a good section of black shales about 600 yards up from the junction. Gritty greywackes and dark blue shales appear in the lower part of the section, the strata next the black shales on the south side consisting of dark blue shales, sandy and micaceous. The black shales next these sandy shales yield *Diplograptus foliaceus* and *Acrothele granulata*. Further up

black shales are well displayed, much crushed and shattery, so that graptolites are not easily obtained from them. The following forms were collected at the bend of the stream:

Cœnograptus gracilis (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *elegans?* (Carr.)

Another exposure of black shales occurs in the Cog Burn about 120 yards above the point of junction with the Glenlosk Burn. Smashed and cleaved black shales are there seen next to the greywackes on the north side of the fold. A few yards west from the junction, on the left bank of the stream, well-preserved graptolites occur in flaggy black shales. The following assemblage of fossils was obtained from these shales, the specimens of *Lasiograptus margaritatus* being particularly fine:

Climacograptus bicornis (Hall.)
,, *tridentatus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *patulosus* (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus margaritatus (Lapw.)
Diplograptus foliaceus (Murch.)
Climacograptus cælatus var. *antiquus* (Lapw.)
Acrothele granulata (Linnr.)

In the Black Grain—a tributary of the north branch of the Cog Burn—three outcrops of the radiolarian cherts appear on separate folds. The cherts are associated with black shales on the two folds furthest down the stream; in the third, the greywackes are in contact with the cherts. The black shales are so greatly shattered that they cannot be expected to yield graptolites.

Conrig Burn (one mile N. of Sanquhar).—In this burn, at a point about a quarter of a mile above its junction with the Crawick Water and a few yards above the bridge leading to Conrig Farmhouse, the diabase-lava is to be seen on the left bank. This rock is of the type so common in the Southern Uplands. It weathers with a rounded pillow-shaped surface, and in fresh fracture is very vesicular. To the east of this lava a band of breccia contains fragments of chert containing radiolaria, and is succeeded by greywackes and shales. Further down, a more acid slaggy lava appears in the bed of the stream, followed by an agglomerate with rounded blocks of slaggy lava. A few yards above the bridge, a small exposure of cherts shows also a pale grey vesicular igneous rock. At the bridge dark shaly clays appear, followed by massive greywackes.

Fingland Burn (Tributary of the Loch Burn, 1½ mile N.E. of Sanquhar).—Nearly in the line of strike of the arch in the Conrig Burn, the volcanic rocks are exposed further to the north-east in Fingland Burn, and again on Conrig Hill. In the Fingland Burn they consist mainly of tuff, visible at intervals in the stream for a distance of about 130 yards, and also in a quarry at the road-side about 430 yards south of Mossholm,

where the rock has been quarried for building stone. This quarry is now partly covered with grass, but the rock still protrudes through the surface in two or three places. It is a grey tuff, composed of sub-angular and rounded fragments of various slaggy lavas. The largest fragment observed was 1¼ inch long by ¾ of an inch broad. One of the types of lava represented among these blocks is a pale grey diabase full of minute rounded vesicles filled with zeolitic materials with a black glazed surface. Another type is a pink vesicular diabase. Here and there occasional crystals of augite occur, together with other minerals which are probably decomposed pyroxenes. Some of the finer-grained fragments of lava have green minerals as inclusions. The matrix is cemented by carbonate of lime. The average size of the volcanic fragments is small, but in a hand specimen its fragmental character is very apparent. The tuff is nearly vertical and its strike is E. 20° N.

On the north side of the quarry a few feet of fine-grained slaggy diabase-lava appears, like some of the fragments in the tuff. From the blocks of lava in the adjoining walls, which seem to have been quarried at this spot, it is probable that a thin sheet of lava is here associated with the tuff. Under the microscope the latter rock is identical with many of the pillowy lavas associated with the Arenig cherts.

In the ascent of the Fingland Burn, the first exposure of the tuff is to be seen nearly opposite the quarry just referred to. Here the same vertical arrangement of the constituents is observable. A mass of fine-grained slaggy lava, about two feet across, occurs at the south end of the stream section; but may be merely a large included block in the tuff. Beyond this outcrop of tuff, at a distance of 40 feet, a band of shale, about one foot thick, is visible in the bed of the stream. Here follows a blank in the section for four yards, when the tuff again appears with sub-angular fragments of lava. The most northerly exposure occurs about 80 yards south of the bridge leading to Clenries, where fresh specimens were procured. There is another blank in the section above this point, but underneath the bridge leading to Clenries Farmhouse blue shales are seen. No evidence appears in the Fingland Burn to show the relation of the tuff to the radiolarian cherts or younger sediments, or the continuance of this arch to the south-west as far as the Conrig Burn, nor is there any proof of the continuation of the tuff as far as the arch of lava on Conrig Hill.

Conrig Hill (Three miles N.E. from Sanquhar).—On the south-west slope of the Conrig Hill, about the 1250-feet contour line, and much in the same line of strike as the volcanic tuff in the Fingland Burn, another exposure of igneous rock is to be found. The two outcrops cannot be continuous, however, on the surface, for on the slope of the Conrig Hill, about the 1000-feet contour line, greywackes and grit can be seen on the slope at short intervals. The arch, now to be described, is of considerable importance, because it shows the relation of the

Arenig lava to the radiolarian cherts, while in an adjoining fold there is a sequence from the cherts to Glenkiln black shales covered apparently unconformably by a brecciated grit or conglomerate.

The lava occurs on the north side of a grassy gully occupied in wet weather by a stream which issues from a spring. The grey and dark cherts, charged with radiolaria, are seen in two exposures on the south side of the hollow, dipping towards the N.N.W. underneath the lava. The first exposure of lava met with in the hollow is highly decomposed, but a few yards further up, the same rock, in a fresher condition, resembles the lava of Tewsgill, near Abington. Still higher up, the rock assumes the character of a highly vesicular diabase and forms small knobs that project through the grassy covering. The exposed length of the arch of lava is about 125 yards. Along the north side of the fold, the igneous material is not seen in conjunction with any other rock, being concealed by drift, but a few yards northwards the grits and greywackes supervene.

On the south side of the arch, and only a few feet from it, another fold runs parallel with the diabase-lava, in the centre of which grey and dark blue cherts with radiolaria are visible. In this fold also a grassy hollow, formed by a rivulet in wet weather, skirts the edge of the radiolarian cherts. At the head of the gully, black shales, shattery and disturbed, are seen folding round the cherts, while the outer ring of the fold is marked by a band of brecciated grit. The black shales cannot be traced continuously along the south side of the arch, as they are buried under the turf, but they reappear on the south limb of the fold. The bottom of the gully is covered with grass, and there is room for the outcrop of the black shales along the northern limb of the fold. These shales are so shattery and cleaved that graptolites are not easily obtained from them, but after a vigorous search at the eastern end of the fold, certain forms were got, proving the position of this band. Certain typical Glenkiln forms occur, as shown in the following list:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Thamnograptus typus (Hall.)
Dicranograptus ramosus (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)

The breccia above the black shales at the eastern limb of the fold can be traced continuously along the north side of the grassy hollow. Its matrix is a grit, throughout which abundant angular and sub-angular fragments of grey and black chert are scattered, some measuring two inches across. It is apparent that this brecciated grit overlying the Glenkiln black shales indicates a local unconformability at this spot. The cherts must have been exposed either here or near the area of sedimentation.

Certain bands of black shales crop out to the south and southeast of the Conrig Hill. On the moor to the north of Brandleys

Cottage crushed and shattered black shales with thin chert bands are seen in a quarry, and the following fossils were obtained from them:

Dicranograptus minimus (Lapw.)
Diplograptus mucronatus (Hall.)
Glossograptus Hincksi (Hopk.)
Cryptograptus tricornis (Carr.)
Acrothele granulata (Linnr.)
Acrotreta Nicholsoni (Dav.)

In a small tributary of the Coal Burn, one-third of a mile west of Shiel Burn, near Brandleys cottages, to the east of the quarry, beside a sheep ree, black shales are visible, which yielded the following fossils:

Thamnograptus typus (Hall.)
,, *scoticus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus zic-zac (Lapw.)
,, *minimus* (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus moffatensis (Carr.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Corynoides calycularis (Nich.)
Diplograptus foliaceus (Murch.)

About 90 yards up this stream from the sheep ree, an interesting section of black shale occurs in which the shale varies in tint from dark blue to black, breaks into fine slabs, and yields a peculiar assemblage of graptolites, which probably indicate the horizon of the base of the Lower Hartfell group. The following forms were here obtained:

Climacograptus bicornis (Hall.)
,, var. *tridentatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus caudatus (Lapw.)
,, *Schärenbergi* (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

There is here no great variety of forms, but their mode of occurrence is noteworthy. Some of the slabs are crowded with *Corynoides calycularis*, others with *Acrotreta Nicholsoni*. Another characteristic is the prevalence of a species of *Climacograptus* of the *caudatus* type.

Towards the col at the head of the Shiel Burn, on the south-east side of Conrig Hill, shattery dark shales are seen in a gully at the head of a stream that drains into the Cog Burn. They contain *Cryptograptus tricornis*, *Climacograptus bicornis*, *Dicellograptus sextans*, *D. patulosus*, *Lasiograptus bimucronatus*, *D. foliaceus*, and *Acrotreta*.

Glendyne Burn.—This stream, an important tributary of the Menock Water, drains the high ground south-west of Wanlockhead. About a mile from the head of the stream, several small exposures of the volcanic zone beneath the radiolarian cherts are interesting, because the character of the lava on the various folds closely resembles that of the fine-grained diabase type so common in the Ballantrae and other areas. On the south slope of the Glendyne Burn, solid rock gives rise to debris. Just below the point where the Rough Cleuch joins the

main stream the radiolarian cherts are seen, overlain by about 30 feet of diabase-lava forming the core of an isoclinal fold; which is succeeded on the slope by the cherts and a second small exposure of the lava and cherts. These are followed by greywackes, grits, and shales, but at one or two points thin seams of shattered black shales intervene between the cherts and greywackes. These are too much shattered and corrugated to yield more than traces of graptolites. Further down the stream, but only a short distance off, the Arenig lava again appears on the south slope, associated with the radiolarian cherts and black shales, which contain the following among other fossils: *Corynoides calycularis*, *Diplograptus foliaceus*, and *Cryptograptus tricornis*. The black shale is here lumpy, and yields graptolites sparingly.

Lower in the glen, the radiolarian cherts are again seen at the head of a small gully on the south side of the valley—probably a continuation of the fold that reveals the lava higher up the Nether Rough Cleuch. At a small tributary of the Glendyne, from the south, the radiolarian cherts and black shales are met with on two separate folds, distant about 50 yards from each other. In the southmost exposure the black shales appear only on the north side of the cherts, while in the more northerly fold the black shales occur on both sides of the radiolarian zone. On the north side of the latter fold the black shales, though reduplicated by folding and much shattered and crushed, have supplied the following fossils:

Cœnograptus surcularis (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Climacograptus Schärenbergi (Lapw.)
Dicellograptus sextans (Hall.)
Corynoides calycularis (Nich.)

In the higher reaches of the Glendyne Burn, rocky scars display the clayey shales with abundant white mica, which overlie the Glenkiln black shales. Weathering with a yellowish tinge, and containing occasionally more sandy layers, they closely resemble the yellow shales yielding *Maclurea* in the Carcoside Burn.

CHAPTER XV.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC FORMATIONS OF THE LEADHILLS DISTRICT—*continued.*

We may now trace the black shale bands which lie within a belt extending from Bail Hill, three miles north-west from Sanquhar, by Kiln Burn, Spotfore Burn, and Corsebank, in the basin of the Crawick Water, to Snar Castle and the Shiel Burn south of Crawfordjohn. This belt of ground furnishes evidence of the lateral modification of the Lower Hartfell group in the direction of the northern margin of the tableland. While the Glenkiln Shales in the neighbourhood of Bail Hill still present the normal lithological type of the Moffat region with their zonal fossils, the highest zone of the Hartfell black shales has disappeared, and its persistent form *Climacograptus caudatus* occurs in a thin dark seam in brown sandy shales near Carco, east of Bail Hill. No less interesting is the important development of Silurian volcanic rocks on Bail Hill, and the bands of andesite-lava and tuff interstratified with the Lower Caradoc Rocks of Craignorth Hill and other localities. While describing the various outcrops of the Moffat series along this belt of ground, we ought to point out that they occur on various compound folds separated by coarser sediments, some of which are composed of conglomerates indicating local unconformabilities. It ought further to be borne in mind that the black shale bands can be traced for no great distance, as they are buried to the north-east and south-west under younger deposits.

Bail Hill Volcanic Area.—By far the most important volcanic area in the Silurian Tableland, after that of Ballantrae, is to be found round Bail Hill, about three miles north-west of Sanquhar. Truncated on the west side by the fault which bounds the Carboniferous basin of Upper Nithsdale, the volcanic materials occupy an area of about three-quarters of a square mile, and rise to a height of 1474 feet on Bail Hill. Small though it be, this limited tract is remarkable for the peculiar types of lava and agglomerate which it contains. Several stream sections traverse the western slope, but the volcanic rocks may be studied to advantage on the numerous rocky knolls near Cat Cleuch and to the south-west of Bail Hill (Figs. 73, 74, 75).

The physical relations of the strata point to the conclusion that these volcanic materials were erupted mainly during Arenig time, for the Arenig cherts are found in contact with them at

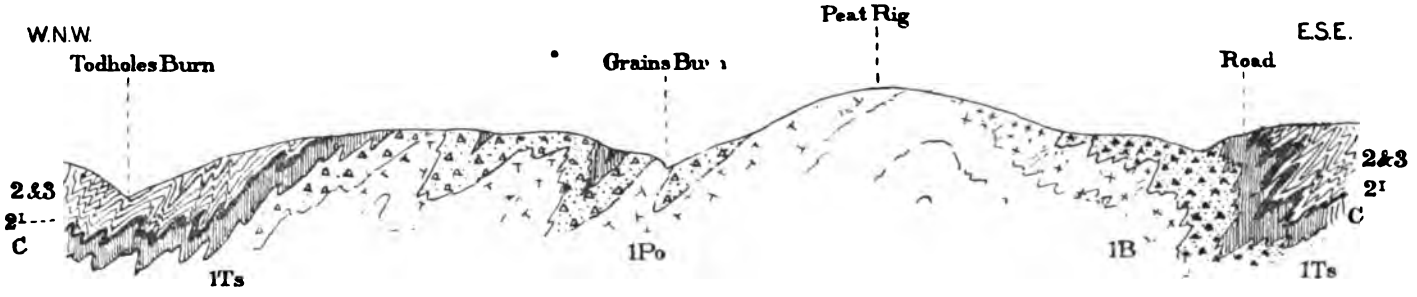


FIG. 73.—Section across the Bail Hill Volcanic Area, from Todholes Burn to Old Road, a quarter of a mile north of Towerhill. (Length, one mile and a half.)

1B. Diabase lavas. 1Po. Mica-andesite lava. 1Ts. Agglomerate (Arenig). C. Radiolarian cherts. 2¹. Glenkiln Shales. 2 & 3. Llandeilo-Caradoc series.

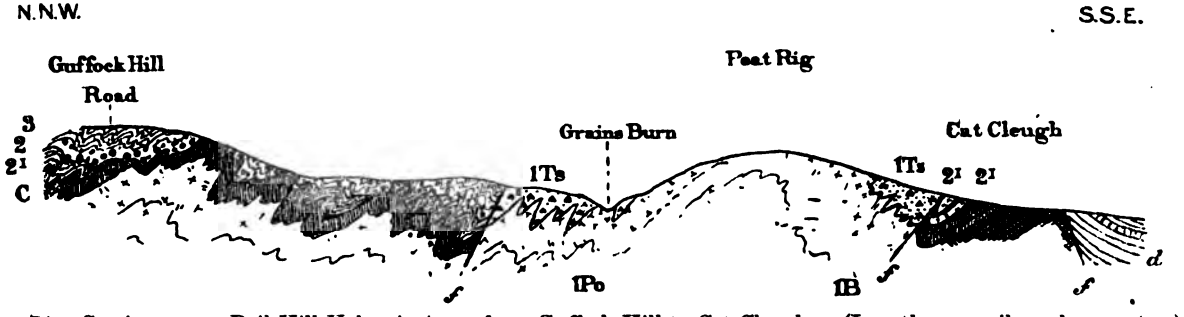


FIG. 74.—Section across Bail Hill Volcanic Area, from Guffock Hill to Cat Cleugh. (Length, one mile and a quarter.)

1 B. Diabase lava. 1Po. Mica-andesite lava. 1Ts. Agglomerate (Arenig). C. Radiolarian chert. 2¹. Glenkiln shales. 2. Greywacke and shales (Llandeilo). 3. Conglomerate, greywacke, and shales (Caradoc?). d. Carboniferous series. f. Fault.

the south-east margin, and small outliers of chert likewise occur within the volcanic area. But while this is true, there are certain sections in the southern part of the tract where lavas are so interstratified with black shales yielding Glenkiln graptolites as to suggest that some local eruptions may have taken place in Upper Llandeilo time.

At the south-east boundary of the tract, near the margin of the Sanquhar coal-field, a small burn, named the Cat Cleuch, a tributary of the Tower Burn, traverses a part of the volcanic area. Near the spot where this stream crosses the old road between Sanquhar and Muirkirk, an excellent section may be seen of highly puckered green cherts with abundant radiolaria (C. Fig. 73, E.S.E. limit of section), associated with a thin band of ashy material. Descending the slope to a point about 100 yards south-west of the hill-road we find the radiolarian cherts close to volcanic agglomerate (1Ts, Fig. 73, E.S.E. limit of section). The junction is not visible, as it is covered with turf, but the distance between the two rocks is not more than a few feet. A microscopic section (No. 6817) of a specimen taken from the agglomerate at this locality shows that the "rock is composed of detached crystals of augite, hornblende, and felspar, and fragments of andestic rocks. The rock fragments are not all of the same type; some contain large phenocrysts of plagioclase and hornblende, similar to those which occur isolated in the rock, in a microlitic matrix; others are without phenocrysts. One fragment is mainly composed of microlitic felspars which show a tendency to assume a feathery mode of aggregation." The foregoing type of hornblende-andesite-tuff is met with on the slope towards the sheep-ree and the stone fence that crosses the Cat Cleuch Burn. A specimen (No. 6818) taken from the rocky knolls just above this fence shows under the microscope "crystals and crystal fragments of pale brown hornblende very abundant, fragments of felspar and augite much less abundant, and somewhat vague rock fragments."

On the other side of the stone fence near the sheep-ree in the Cat Cleuch, fine-grained tuff appears with augite crystals. On the east bank brecciated black shales occur, in contact with the fine-grained tuff. Further down, on the same bank, black shales yield Glenkiln graptolites, followed by radiolarian cherts. On the opposite bank, about 100 yards below the stone fence, from a small exposure of black shales, the following Glenkiln graptolites in fairly good preservation were collected:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
,, *peltifer* (Lapw.)
Glossograptus Hincksi (Hopk.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)

A few yards down stream from this section of black shales, an intrusive igneous rock, resembling a mica-trap, occurs in the

course of the burn where it traverses the radiolarian cherts. Near the spot where the fault that bounds the Carboniferous basin crosses the Cat Cleuch, the latter receives a small tributary on the north side, which furnishes the following section. In the lower part of its course the intrusive rock just referred to appears where it clearly pierces the radiolarian cherts. The microscopic examination of a specimen (No. 6816) from this locality shows that the rock contains "phenocrysts of biotite, felspar (altered, but apparently for the most part plagioclase), and apatite, in a reddish-brown turbid matrix with carbonates. The apatite occurs in considerable abundance as limpid crystals, which are often as large as the porphyritic felspars." In general appearance the rock resembles a mica-trap.

About 200 yards above the point where this tributary joins the Cat Cleuch, evidence bearing on the relation of the lavas to the Glenkiln Shales and Arenig cherts is visible. The radiolarian cherts appear at a bend in the burn, followed by black shales and volcanic rocks; and these are in turn succeeded by 27 feet of black shales, which contain graptolites in fairly good preservation, proving the Glenkiln horizon of the shales, as shown in the following list:

Didymograptus superstes (Lapw.)
Cœnograptus sp.
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Dicranograptus ramosus (Hall.)
Climacograptus bicornis (Hall.)
Glossograptus Hincksi (Hopk.)

At a spot about three feet from the northern margin of the band the following forms were obtained: *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Climacograptus Schärenbergi*, *Cryptograptus tricornis*. These black shales are followed by a bed of diabase-lava three feet thick, and a band of black shales two and a half feet thick, yielding *Dicellograptus sextans*, *Diplograptus foliaceus*, *Climacograptus*, succeeded in turn by slaggy diabase-lava. As the junction between the lava and the black shales was here exposed, and no fault seemed to intervene, it is not improbable that these thin lava-sheets may point to contemporaneous volcanic action in Upper Llandeilo time.

Above this point the stream lays bare a fine section of the tuff. Though in places the rock at first sight resembles a lava, its fragmental character is apparent on a weathered face. A conspicuous feature in it is the abundance of large crystals of augite which project on the weathered surfaces, and which, where the matrix is highly decomposed, can easily be removed. The largest crystal observed in the field measured about an inch across, but this is quite exceptional. Under the microscope, a specimen of the rock taken from this locality (No. 6819) is found to be a tuff composed "of large fragments of a coarsely porphyritic augite-andesite. The augite crystals show the common forms, and are yellowish in thin sections. The felspar crystals polarise as aggregates, and are indeterminable in con-

sequence of alteration. It is interesting to note that both hornblende- and augite-andesites have been broken up to form these tuffs." (1 Ts, Figs. 73, 74, E.S.E. limit of sections.)

Westwards this peculiar tuff and agglomerate can be traced for a distance of 300 yards south of the stone fence already mentioned, where it contains well-rounded blocks of various igneous rocks, including gabbro, diorite, granite, andesite, and lava of a more acid type than any found in the neighbourhood. A similar coarse agglomerate, charged with blocks of gabbro and pink and grey granite, is visible at a point about 550 yards up the west tributary of the Cat Cleuch. Close to this exposure a band of fine-grained andesite or diabase-lava comes to the surface.

In the streams and on the hill slopes, north-westwards across the area in a direction parallel to the fault bounding the Sanquhar coal-field, the volcanic rocks are exposed. The coarse agglomerate just referred to is succeeded by green fine-grained diabase, followed by a mass of agglomerate containing fragments of lava and blocks of a pink granitoid rock, which is visible on the slope about the level of the 1000-feet contour line. Further to the north-west, a small scar cut by a streamlet on the S.S.W. slope of Peat Rig (Figs. 73, 74) gives an excellent exposure of porphyritic lava closely resembling the beautiful diabase-porphyrite at the mouth of the Currarie Burn, Ayrshire. Northwards a distance of 500 yards the volcanic rocks are met with in occasional knobs on the slope. Beyond a patch of covered ground the Grains Burn traverses the north-west part of the

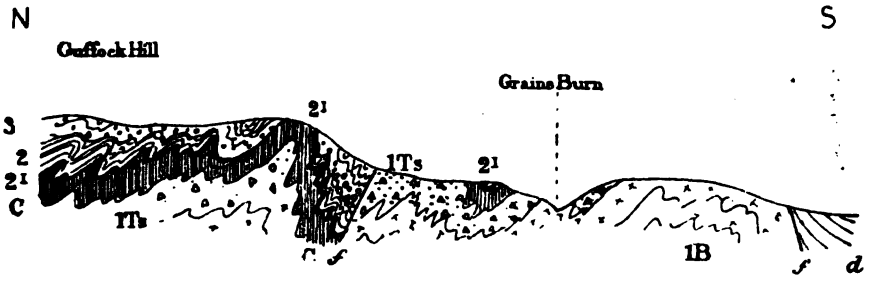


FIG. 75.—Section across Bail Hill Volcanic Area, from Guffock Hill to Sanquhar Coalfield. (Length, one mile.)

1B. Diabase lavas. 1Ts. Agglomerate (Arenig). 2¹. Glenkiln Shales. 2. Greywacke and shales (Llandeilo). 3. Conglomerate, &c. (Caradoc). d. Carboniferous series. f. Faults.

volcanic area. In this stream above the point where it is crossed by the fault bounding the Sanquhar coal-field, slaggy lava with elongated vesicles is visible, followed by rather fine-grained agglomerate with sub-angular fragments of igneous rocks. In a rocky gorge a remarkable rock is to be seen, having a fine-grained matrix with porphyritic felspar and biotite. Under the microscope (No. 6820) it shows "phenocrysts of altered

felspar and biotite in a microlitic ground-mass," and has been termed by Mr. Teall a biotite-andesite (1 Po, Fig. 73).

About half a mile above the Sanquhar basin, the Grains Burn divides, one branch running south from the slope of Guffock Hill. The lower part of this rivulet crosses the biotite-andesite, which is succeeded northwards by a well-marked agglomerate which dips towards the north and contains small, well-rounded blocks of biotite-andesite (1 Ts, N.N.W. of Grains Burn, Fig. 74). About 130 yards above the fork, this agglomerate is abruptly truncated by a fault (f, N.N.W. of Grains Burn, Fig. 74), which brings slightly conglomeratic greywackes and shales in contact with the volcanic series. At the fault, pebbles of the Arenig igneous rocks are found in the conglomerate, probably indicating that these volcanic rocks may have been exposed to denudation before the overlying conglomerate was formed.

Returning now to the hill slope north of the Grains Burn, the observer finds biotite-andesite lava at intervals for a distance of 200 yards north-west of that stream. Near this spot, within the volcanic area, black shales and cherts form a small patch about 70 yards north-east from the edge of the Carboniferous rocks (C, 2^1, Figs. 73, 75, N. of Grains Burn). A second patch of red mudstones and radiolarian cherts appears about 100 yards further to the north, followed by the lava for a distance of about 100 yards. This is the most northerly exposure of the volcanic rocks near the Carboniferous basin (Fig. 73). A third patch of radiolarian cherts and mudstones with black shales appears within the volcanic area to the east of those just described, and almost due south of Guffock Hill.

On Bail Hill, which forms the north-eastern part of the volcanic area, there are few exposures of solid rock; but to the south-east of the cairn, and not far from the top, diabase-lava is visible at a point where a quarry has been opened for dyke-building. The lava is also seen on the northern spur of the same hill.

The volcanic materials within this limited area comprise lavas of andesite, diabase, diabase-porphyrite, and biotite-andesite; while the pyroclastic materials include augite- and hornblende-andesite tuff, biotite-andesite tuff, and agglomerate. The character of the agglomerates and their prominent development within such a small area probably point out the site of an old volcano in Arenig time.

We must now consider the relations of these Arenig volcanic rocks to the overlying sediments along the north and east sides of the tract. Along the north side a fine development of Arenig cherts may be seen, but not in immediate contact with the lavas. From a point near the margin of the coal-field they can be traced eastwards over the crest of the Guffock Hill in the direction of the Kiln Burn. Black shales, with imperfectly preserved graptolites, are associated with these cherts near the margin of the coal-field and on both sides of the outcrop of Guffock Hill, but at one or two spots these black shales yield a characteristic

assemblage of Glenkiln forms (2^1, Fig. 75, Guffock Hill). The sediments in visible contact with the Arenig lavas and tuffs on the north side of the area are younger than the Arenig cherts, and probably form part of an unconformable series, because they contain rounded blocks of the volcanic rocks. Moreover, they are brought into their present position by the fault already referred to (Fig. 75), which is seen in the small branch of the Grains Burn that drains the south slope of Guffock Hill.

Returning to the section laid bare in the tributary of the Grains Burn just referred to, and ascending that tributary from the margin of the volcanic rocks, we find conglomerate, greywackes, shales, and grits for a short distance. These are succeeded by black shales exposed on three separate anticlines, with greywackes and shales intervening. About 250 yards above the fault the following Glenkiln assemblage of fossils was obtained:

Didymograptus superstes (Lapw.)
Cœnograptus sp.
Dicranograptus ramosus (Hall.)
,, *minimus* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus euglyphus (Lapw.)
Lasiograptus bimucronatus (Nich.)
Climacograptus bicornis (Hall.)
Glossograptus Hincksi (Hopk.)
Dicellograptus moffatensis (Carr.)

Further up stream, on another fold of the Moffat series, a limestone nodule, from two to three feet long, was observed in the black shales, which afforded the following forms: *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Diplograptus euglyphus*, *Climacograptus*, and *Acrothele granulata*. These strata are succeeded by blue shales with thin bands of greywacke, and, after a blank in the section, by a fine development of radiolarian cherts which continues for some distance up stream. Northwards they are followed by dark blue shales up to the old hill-road (Fig. 74, Guffock Hill, Road).

About 500 yards to the west of the same tributary, a dry gully descends the south slope of Guffock Hill, which, running nearly north and south, exposes a section along part of its course. In the higher portion, the black shales come to the surface on the north limb of a fold of Arenig cherts (2^1, Fig. 75), but south of this zone there is a blank in the section for a short distance; soon, however, grey shales appear with black strains, followed by a conglomerate in immediate contact with the volcanic rocks.

Along the east side of the Bail Hill area, the relations of the volcanic zone to the overlying sediments are buried under a covering of turf and drift, but the radiolarian cherts are seen at two or three localities, as, for example, on the moor about 700 yards S.S.E. of the top of Bail Hill, and at the head of the Stoodfold Burn, a tributary of the Kiln Burn.

Kiln Burn.—Immediately to the north of Bail Hill, two small streams unite to form the head-waters of the Kiln Burn, which flows southwards to join the Crawick Water north of Carco Mains. Various folds of the Arenig cherts and Glenkiln

black shales occur in the course of this stream, together with younger sediments, some of which indicate local unconformabilities. Contemporaneous volcanic rocks likewise appear, the horizon of which is defined by the graptolite zones in association with them.

In the westmost branch of the Kiln Burn to the north of Bail Hill, an arch of Arenig cherts and Glenkiln black shales may be seen near the head of the streamlet; indeed, it appears to be the easterly prolongation of the fold of cherts already described as extending from the margin of the coal-field, over the crest of Guffock Hill in the direction of the Kiln Burn. The centre of this arch is occupied by the red cherts, followed by the green cherts, in which radiolaria are abundant. On the north limb of the fold, in normal sequence after the green cherts, come black cherts with clayey shales, succeeded by alternations of black shales with green and white shales like fireclays. The lowest band of black shales yielded the following characteristic assemblage of graptolites belonging to the Glenkiln group:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Diplograptus perexcavatus (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *moffatensis* (Carr.)
Corynoides calycularis (Nich.)
Acrothele granulata (Linnr.)

Northwards these black shales are succeeded by alternations of grey clays and black shales, and at a point about ten yards above the last named fossiliferous locality the black shales furnished:

Climacograptus cœlatus (Lapw.)
Didymograptus superstes (Lapw.)
Cœnograptus sp.
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)

Grey shales and greywackes appear in the stream to the north of this development of the Glenkiln black shales.

On the south side of the arch, the cherts are succeeded by a thin band of crushed black shales, followed by an alternation of greywackes and shales. Within a short distance a band of black shales is met with in the stream, yielding graptolites in a fragmentary form. Further down the stream, grey shales and greywackes are met with as far as a point about 70 yards above a stone fence on the south side of the valley. Here a remarkable conglomerate, evidently indicating a local unconformability, is well seen on both banks of the stream. Its matrix consists of grey and brown clayey or shaly substance, in which are embedded blocks of various materials. The largest of these consist of grey greywacke, which are well rounded, and frequently attain a great

size, some measuring about three feet across. In places the conglomerate consists of an assemblage of angular and sub-angular fragments of black shales, yielding the following typical Glenkiln graptolites: *Didymograptus superstes*, *Dicellograptus*, *Dicranograptus*, *Diplograptus*. The conglomerate rests on black shales, and at this point it is composed chiefly of black shale fragments. Still further down, near the fork of the burn, it contains well-rounded blocks of greywacke, with small fragments of radiolarian chert.

Near the foot of the Sow Burn—a small stream which drains the south slope of the Cocker Hill—a conglomerate occurs with fragments of red cherts, and a little further up black shales appear on the strike of the band in the Kiln Burn that seems to be overlain by the conglomerate. After a blank in the stream, the conglomerate is again seen, followed by grey cherts and black shales, while further up stream the conglomerate is once more exposed in another fold. In this tributary stream there are three outcrops of conglomerate separated by the underlying cherts and black shales. Beyond the final exposures of the conglomerate, black shales are seen, followed by greywackes and shales, the latter occupying a space of 200 yards. These are followed by black shales, grey and green cherts, and by the red cherts, exposed in descending order. The strike of this fold of radiolarian chert and black shales lies further to the north than any of those exposed on the north side of the Bail Hill or in the Kiln Burn. The general dip of the strata in this tributary stream is to the north-west; hence the folds are isoclinal.

Eastwards from its fork the Kiln Burn, north of the top of Bail Hill, for nearly a third of a mile flows obliquely across the strike of an alternating series of conglomerates, greywackes, and shales. The conglomerate along this part of the stream course varies in character—sometimes it is composed chiefly of well-rounded fragments of greywacke, sometimes it is a brecciated mass of radiolarian chert, while again it is made up chiefly of sub-angular fragments of black shales. At the bend where the Kiln Burn flows towards the south, and at the junction of a small streamlet from the north, an excellent example of the last type is seen, where, from one of the included fragments of black shale, the following graptolites were collected: *Didymograptus superstes*, *Cœnograptus gracilis*, *C. pertenuis*. *Diplograptus euglyphus*, *D. foliaceus*, *Climacograptus Schärenbergi*. The conglomerate appears at intervals for a distance of about 100 yards below the marked bend towards the south, and is succeeded by greywackes and grits with black shale galls, and eventually by dark blue micaceous and felspathic shales, with fragments of graptolites, including *Dicranograptus ramosus* and *Climacograptus Schärenbergi*, the average dip of the strata being towards the N.N.W. at 60°.

At the foot of the Stoodfold Burn, that joins the Kiln Burn about three-quarters of a mile north of Carcoside, a small development of volcanic rocks may be seen which evidently

occupy a higher horizon than those of Arenig age. They extend westwards along the south bank of the Stoodfold Burn for a distance of 300 yards, where a volcanic breccia is visible, containing rounded bombs of diabase-lava, and on the top of the same bank, slaggy diabase-lava, like the blocks in the tuff, appears. Excellent sections, too, are to be found on the west bank of the Kiln Burn, where the tuff contains minute fragments of black shales. Under the microscope the rock (No. 6825) is found to be "largely composed of fragmentary felspars (mostly plagioclase) and bits of altered igneous rock. Biotite is also present." In the bed of the Kiln Burn below the junction of the streams, the tuff, where it forms a series of cascades, merges into an ashy grit, with recognisable fragments of black shales, and is there interleaved in grey and blue shales. A few yards below these water-falls the agglomerate and lava are visible on the west bank. A microscopic examination of the lava (No. 6824) shows it to be composed of "phenocrysts of idiomorphic hornblende and felspar (the former now only represented by pseudomorphs largely composed of carbonates) in a microlitic matrix," the rock being named by Mr. Teall a hornblende-andesite.

We have now to consider the sediments in contact with this narrow volcanic zone, which does not exceed thirty yards in breadth. On the north side, at the junction of the Stoodfold and Kiln Burns, blue and grey shales dip towards the N.N.W. at angles varying from 50° to 60°; along the strike of these beds, a few yards to the north-east, near the foot of the Shiel Burn—a tributary from the east—certain dark shales afford *Dicranograptus ramosus*, *Climacograptus Schärenbergi*, *Dicellograptus Forchhammeri*, and *Corynoides calycularis*. At a point 350 yards up Stoodfold Burn from its junction with the Kiln Burn dark blue shales succeed, with black seams charged with iron pyrites and containing numerous white specks. The dark seams are fossiliferous, and have yielded the following fossils:

Climacograptus peltifer (Lapw.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
Dicellograptus Forchhammeri (Gein.)
,, *sextans* (Hall.)
Acrotreta Nicholsoni (Dav.)

Again on the south side of the volcanic zone in the Kiln Burn, similar dark blue shales with white specks dip southwards, off the lava, at 60°, yielding *Dicranograptus ramosus* and *Climacograptus Schärenbergi*. From the evidence now adduced it is not improbable that this volcanic zone may be on the horizon of the passage beds between the Glenkiln (Upper Llandeilo) and Hartfell black shales (Lower Caradoc).

In the Kiln Burn below the outcrop of volcanic rocks, flaggy blue shales with yellow calcareous ribs and nodules are followed by massive grits and greywackes, in the midst of which there is

a fold of black shales yielding the following undoubted Glenkiln forms:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus ramosus (Hall.)
,, *formosus* (Hopk.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, ,, var. *B.* (Lapw.)
Corynoides sp.

About 200 yards N.N.W. of Carcoside Farmhouse, in a rivulet joining the Kiln Burn from the south-west, a band of vesicular diabase-lava occurs in the midst of the greywackes, which may probably be of Caradoc age, but no fossiliferous bands were found near it.

Polcraig Burn, Meikle Carco.—Evidence from this section affords further proof that the lithological characters of the Hartfell black shales have undergone modification, for the zonal form, *Climacograptus caudatus*, here occurs in brown sandy shales. The Polcraig Burn rises on the south slope of the Black Hill, and joins the Crawick Water above Meikle Carco. Near the head of this stream grey- and buff-coloured shales with sandy layers, much decomposed, after a careful search furnished gasteropods from certain seams. Among the graptolites the following were recorded: *Glossograptus Hincksi*, *Climacograptus caudatus*, *Dicellograptus elegans*, *D. caduceus*, *Dicranograptus ramosus*, *Cryptograptus tricornis*, which indicate the position of the *Climacograptus caudatus* zone. In the decomposed sandy seams specimens of *Maclurea* (*Ophileta*) *macromphala* (M'Coy) were obtained; indeed, on one slab no fewer than six specimens of *Maclurea* were noted.

Further down the stream, these grey sandy shales with grits and greywackes are met with, together with two outcrops of black shales. The lower and better outcrop, distant about a quarter of a mile from the foot of the stream, yielded graptolites, sometimes in excellent preservation, which are given in the following list:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus patulosus (Lapw.)
,, *sextans* (Hall.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Dicranograptus ramosus (Hall.)

On the north side the greywackes and shales appear to be faulted against the black shales, while on the south side they are regularly interbedded with the graptolite bands.

Spotfore Burn (Tributary of the Crawick Water).—In this stream, above its point of junction with Crawick Water,

blue greywackes and shales appear near the mouth of the glen and at intervals for about half a mile. Opposite the first sheep-fold, barely half a mile up stream, in a little scar on the west side of the valley, a band of black shales, associated with a grey shaly rock like fireclay, contains the following fossils:

Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Glossograptus Hincksi (Hopk.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Leptograptus flaccidus (Hall.)
Diplograptus euglyphus (Lapw.)

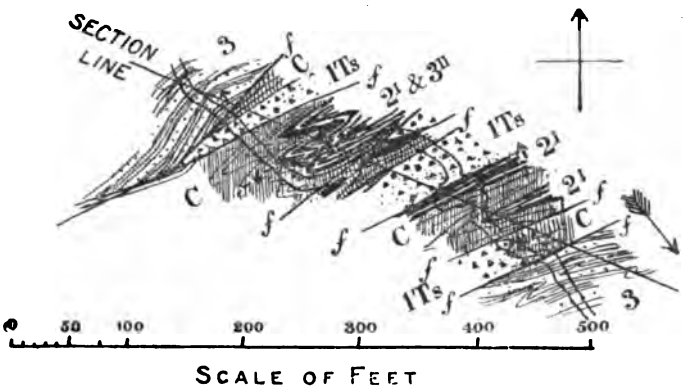


FIG. 76.—Plan of the Strata in Spotfore Burn (at foot of Penfraw Burn).

1B. Diabase lavas. 1Ts. Agglomerate (Arenig). C. Radiolarian chert. 2l. Glenkiln shales. 3ll. Lower Hartfell Shales. 3. Greywacke, &c. (Caradoc). f. Faults.

Higher up the stream we find blue well-bedded sandy and micaceous shales, resembling the fossiliferous blue shales near the volcanic zone in the Kiln Burn, already described. These are followed by grey grits containing black shale galls, till at a bend in the stream below a picturesque water-fall the radiolarian cherts and Glenkiln black shales appear, associated with a band of volcanic agglomerate.

The accompanying ground plan (Fig. 76) shows the relations of the strata. At the south end of the section, a calcareous breccia, composed of angular fragments of chert with radiolaria, is seen close to the grits, and higher up merges into a calcareous tuff visible on the west bank. Here the grey radiolarian cherts form a cliff at the bend on the east bank. After a blank in the section for a short distance, an exposure of black shales is seen with cherts on both sides (C. 2^{l}, E.S.E. of waterfall, Fig. 77). The black shales, at this first exposure on the east bank, are well bedded and platy, yielding in abundance a characteristic assemblage of Glenkiln graptolites—one form in particular, *Didymo-*

graptus superstes, being very plentiful. The following forms were here obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *Schärenbergi* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Dicranograptus ramosus (Hall.)
,, *minimus* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)

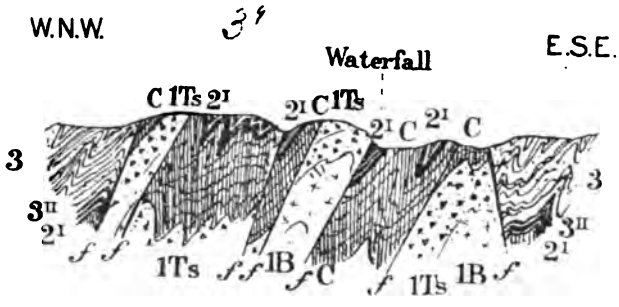


FIG. 77.—Section in Spotfore Burn (at foot of Penfraw Burn).

(Explanation as in Fig. 76.)

Immediately to the north of this the cherts are well seen in the bed of the stream and on both banks. They are followed by Glenkiln black shales on the south side of the agglomerate that forms the waterfall (2¹, Fig. 77). Here the black shales appear to dip beneath the agglomerate as if truncated by a reversed fault. Some of the typical Glenkiln graptolites were found on the bank on the west side of the waterfall in contact with the agglomerate, including *Didymograptus superstes*, *Dicranograptus ramosus*, *Dicellograptus sextans*, and *Climacograptus Schärenbergi*.

The waterfall is formed by a band of volcanic ash or agglomerate (1 Ts, Fig. 77), the matrix of which is of a greenish colour and contains minute lapilli of volcanic materials. Throughout this matrix, conspicuous bombs of a slaggy diabase-lava are scattered, some measuring 18 inches across. They are well seen in the bed of the burn at the top of the waterfall. Another variety of lava is represented among these blocks, viz.: the augite-andesite with well-defined crystals of augite.

Further up the stream, the Glenkiln black shales on the north side of the agglomerate have a thin strip or fold of the radiolarian cherts in the heart of them. It is not improbable that the volcanic tuff may overlie the Glenkiln Shales in this section, a suggestion which is strengthened by the evidence at the head of the Penfraw Burn, to be described presently. At the bend above the waterfall, on the north-east bank, the Glenkiln black shales occur on the grassy slope a few yards from the stream,

where they have furnished the following characteristic Glenkiln forms:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus zic-zac (Lapw.)
Dicranograptus ramosus (Hall.)
Dicellograptus patulosus (Lapw.)
,, *moffatensis* (Carr.)
,, *sextans* (Hall.)
Glossograptus Hincksi (Hopk.)
Diplograptus euglyphus (Bron.)
,, *foliaceus* (Murch.)

From this point the stream flows for a few yards over a rapid alternation of Arenig cherts and Glenkiln black shales, repeated by sharp folds, the cores of which are occupied by the cherts. Some of the folds are normal, others isoclinal.

At the foot of the Penfraw streamlet that joins the Spotfore Burn, seventy yards west of the waterfall, volcanic ash like that just described is visible in the bed of the stream, and is traceable a short distance up the Penfraw section, bounded on the north side by a well-marked fault (1 Ts, Fig. 77, W.N.W. of waterfall). Blue shales and greywackes are laid bare in the lower part of the Penfraw Burn, but at the very head of the stream there is an excellent exposure of volcanic ash, evidently on another fold, as the strike of the beds is to the north of that at the waterfall in the Spotfore Burn. Here the grey and decomposing rock is well seen on the face of a scar, where it weathers spheroidally and exfoliates in such a way that a fresh fracture is not easily obtained. But on the weathered surfaces its pyroclastic character is well defined, the angular and sub-angular volcanic fragments being visible to the naked eye. On the south side of the tuff, and almost in contact with it, black shales dip to the north-west, and yield *Didymograptus superstes* and *Climacograptus bicornis*, suggesting the probability that this band may be later in time than the Arenig volcanic series.

Returning now to the Spotfore Burn section, where it is joined by the Penfraw streamlet, the observer finds that the volcanic ash is bounded on the north side by the fault already indicated. The rock, brecciated at the junction, includes angular fragments of chert with radiolaria. For 300 yards up stream to the foot of the Poltarn Burn, that drains the west slope of Largbrae Head, there is a succession of blue shales and greywacke bands like those of the Kiln Burn. Ten yards beyond the junction of the streams, conglomerate appears, charged with well-rounded fragments of greywacke, set in a matrix of shaly greywacke. From 20 to 30 yards above the foot of the Poltarn Burn, the radiolarian cherts are seen in the stream with the conglomerate resting on them unconformably. Thence to a spot not far above the foot of the Polholm Burn, that joins the Spotfore Burn half a mile west of Largbrae Head—a distance of about 300 yards—the cherts are visible either in the bed or banks of the stream, with the conglomerate resting directly on them. This appears to be a local unconformability, resembling that between the

Benan conglomerate and the Arenig volcanic rocks north of the Stinchar. The denudation which marks it had not proceeded far enough to reveal the volcanic zone, and hence the comparative absence of volcanic blocks in the conglomerate. The cherts and overlying conglomerates are so rapidly folded together that the cherts do not extend far up the slopes of the valley. An interesting feature of these cherts is the occurrence of very thin layers of fine ashy material interleaved in them.

In the rocky gorge a few yards above the junction of the Polholm Burn, a fragment of black shale in the conglomerate was found to contain Glenkiln graptolites (*Didymograptus superstes*, &c.). From this point the conglomerate extends up the stream for two-thirds of a mile. In the scars on the south side of the Spotfore Burn the cherts are visible. The conglomerate is also seen in the Polholm Burn near the foot, and again in the Shiel Burn half a mile to the west, near its point of junction with the Spotfore Burn. A continuous section of the conglomerate has been cut by the Shiel Burn between the sheep-ree and the foot of the burn. Here the conglomerate has a shaly matrix with well-rounded pebbles of greywacke and grit.

Back Burn (Tributary of the Crawick Water).—This stream rises on the slopes of the Shiel Hill, and flows south-east to join the Crawick Water below Nether Cog. Ascending this stream from its point of junction with the Crawick Water, we find grey greywackes and blue shales, the former merging into massive grits, till about 600 yards from the foot we reach an exposure of black shales, which yielded the following among other fossils:

Didymograptus superstes (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Dicellograptus moffatensis (Carr.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)

The black shales again appear at the mouth of a tributary burn, where they are traversed by a small fault. For about 100 yards the black shales come to the surface several times, with intervening greywackes, grits, and blue shales. Further up, the stream flows over a fine succession of blue and grey shales like those in Kiln Burn, which are sparingly fossiliferous. A few yards above the point where a streamlet joins the Back Burn from the east, the following fossils were found in blue shales: *Climacograptus Schärenbergi*, *Dicranograptus ramosus*, *Diplograptus*, *Acrotreta Nicholsoni*. This fine development of blue shales which from the included fossils are probably of Caradoc age, is eventually succeeded by pebbly grits and conglomerates, with well-rounded pebbles of greywacke, visible in the stream as far as the bend below the fork of the burns. Here a fine outcrop of black shales, upwards of 100 yards in breadth, is laid open in the stream. Although repeated by folds, these strata yield graptolites in profusion and in excellent preservation. Certain layers on the east bank of the stream at the bend

are crowded with characteristic Glenkiln forms. Lithologically the black shales differ from the black cherty bands with black shale partings belonging to this horizon in the Moffat area. They are flaggy and platy in character. The following fossils were here obtained:

Didymograptus superstes (Lapw.)
Cænograptus gracilis (Hall.)
,, *nitidulus* (Lapw.)
,, *surcularis* (Hall.)
,, *pertenuis* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus rugosus (Emm.)
,, *foliaceus* (Murch.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)
Climacograptus sp. nov.
,, *cælatus*, var. *antiquus* (Lapw.)
Climacograptus Schärenbergi (Lapw.)
,, *peltifer* (Lapw.)
Dicellograptus moffatensis (Carr.)
,, *divaricatus* (Hall.)
,, *sextans* (Hall.)
Leptograptus flaccidus (Hall.)
Dicranograptus formosus (Hopk.)
,, *ramosus* (Hall.)
Thamnograptus typus (Hall.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

To the north of this point, as far as the head of the burn, blue and grey grits and shales appear. At the head of the tributary which rises on the south-east flank of Shiel Hill the conglomerate is exposed.

Polthistly Burn (Tributary of the Crawick Water at Corsebank).—This burn, about two-thirds of a mile in length, drains the northern slope of the Crucreach Hill. Near its head, between the 1000 and 1250 feet contour-lines, black shales may be seen in a branch of the stream. From the following list of fossils obtained here there can be little doubt that these strata belong to the Glenkiln horizon:

Didymograptus superstes (Lapw.)
Dicranograptus ramosus (Hall.)
,, *minimus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *intortus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *Schärenbergi* (Lapw.)
Cænograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)

From the manner in which the black shales strike at the conglomerate in this scar, it is probable that the two are brought together by a fault. It would seem that the radiolarian cherts are not far from the surface here, for their debris is visible at intervals in the line of strike eastwards in the direction of Corsebank. At one point they appear about a quarter of a mile from the scar of black shales. We may reasonably infer that they form the core of the arch, and are followed on the south side by the Glenkiln black shales.

On the southern slope of Craignorth Hill, below Corsebank, a rocky gorge has been cut by a small stream, near the foot of which dark blue flaggy shales crop out, much jointed and traversed by faults. Just above the point where this burn takes a bend to the south-east a band of volcanic ash occurs in

the middle of the gully, but owing to a talus of debris the relations of this band to the surrounding rocks are not apparent. On the slope, however, on the north-east side of the stream, the ash is brought into contact with the blue flags by a fault. A microscopic section (No. 6829) from this latter outcrop shows the rock to consist of "felspar fragments and fragments of hornblende and mica-andesite. Felspars and bisilicates decomposed." The rock has been termed by Mr. Teall an andesitic tuff. A few yards to the right of this exposure, the volcanic ash is seen to be regularly interbedded with the sediments. On the cliff to the right three bands of ashy material are intercalated in the dark blue shales, two of them about one foot thick each, while the third is several feet across. Here in blue-black shales the following fossils were obtained:

Dicellograptus sextans (Hall.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Climacograptus Schärenbergi (Lapw.)
Diplograptus foliaceus (Murch.)
Glossograptus Hincksi (Hopk.)

On the cliff further up the gorge, the volcanic ash again appears, and beyond it, blue-black flaggy shales, which are well seen in the bed of the burn, extend for a few feet up stream. This locality is just a few yards below the point where the stream bends to the E.N.E. Fossils occur here in fine preservation, as given in the following list:

Dicranograptus ramosus (Hall.)
Leptograptus flaccidus (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *moffatensis* (Carr.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus Schärenbergi (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)
Hyalostelia fasciculus (M'Coy.)

As this band evidently represents the passage beds between the Glenkiln and Hartfell divisions, it is reasonable to infer that the bands of volcanic ash may belong to the same horizon.

Eller Scaur.—At the side of the road leading to Sanquhar, below Corsebank on Crawick Water, an excellent section of black shales may be seen, from which the following fossils have been obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
Dicranograptus minimus (Lapw.)
,, *zic-zac* (Lapw.)
,, *ramosus* (Hall.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *intortus* (Lapw.)
,, *moffatensis* (Carr.)
,, *patulosus*, var. *B.* (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Leptograptus flaccidus (Hall.)

Wanlock Water (Lower Section).—Towards the foot of this stream, opposite Clackleith shepherd's house, grey and blue shales with grits and greywackes are traversed by a peculiar

type of igneous rock, like that in the small stream on the south side of the Craignorth Hill, just described. At a point about 60 yards below the mouth of Clackleith Burn, an exposure of black shales alongside of greywackes has yielded the following fossils: *Dicranograptus ramosus*, *Climacograptus bicornis*, *Cryptograptus tricornis*, *Diplograptus foliaceus*, and *Didymograptus superstes*. In the scar on the other side of the Wanlock Water, nearly opposite the north end of the wall bounding the enclosed field at Clackleith, the prolongation of this shale band is exposed, where the following Glenkiln forms were obtained: *Didymograptus superstes*, *Diplograptus foliaceus*, *Dicranograptus ramosus*, *D. sextans*, *Climacograptus bicornis* (?), *Cœnograptus surcularis*, and *Dicellograptus moffatensis*. About 30 yards down stream black shales again appear, from which *D. superstes*, *Climacograptus bicornis*, *Dicranograptus ramosus*, *D. Forchhammeri*, and *Cryptograptus tricornis* have been collected. About 200 yards still lower certain peculiar blue shales visible in the stream resemble those in Craignorth Burn.

Glenrae Burn.—In this stream, that joins the Crawick Water three-quarters of a mile above Spango Bridge, brown sandy shales are visible in the lower part of the section, associated in places with bands of pebbly grit like the Snar Water conglomerate and grit. At a point about a third of a mile above the foot of the burn, dark sandy lumpy shales are exposed, which yield a few graptolites. Beyond this point, alternations of shattery brown shales or mudstones with brown-weathering grits, probably on the horizon of the Duntercleuch grits, are exposed at intervals. About half a mile up the stream, at a point not far from where it branches, black shales are well displayed in a compound anticline. On the north side of the northmost fold, where they are seen in contact with grey shales, they are well bedded or platy and abundantly charged with well-preserved graptolites. They occupy the left bank for a distance of about twelve feet, until succeeded southwards by brown-crusted greywackes and shales of the same type as those on the north side of the fold. The following list of fossils obtained from this locality indicates that the strata which contain them belong to the lower portion of the Hartfell black shale group.

Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
,, *Clingani* (Carr.)
Diplograptus foliaceus (Murch.)
Glossograptus Hincksi (Hopk.)
Dicellograptus Forchhammeri (Gein.)
,, *elegans* (Carr.)
,, *sextans* (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Leptograptus flaccidus (Hall.)
,, *capillaris* (Carr.)
Amphigraptus sp.
Corymoides calycularis (Nich.)
Siphonotreta micula (M'Coy.)
Hyalostelia fasciculus (M'Coy.)

Further up stream, black shales too much crushed to yield recognisable graptolites cover a space of about thirty yards, and appear again still higher in a third anticline in a similarly crushed and disturbed condition.

Nether Whitecleuch Burn (Crawick Water).—The small branches at the head of this burn expose black shales, with clays so much shattered and disturbed that graptolites are difficult to obtain from them, but fragments of *Dicranograptus ramosus*, *Climacograptus*, *Diplograptus*, were here collected. A bed of breccia occurs near at hand, but its relations cannot be satisfactorily determined owing to the disturbance of the beds. Near the fork, pebbly grit and conglomerate with large boulders of greywacke are seen for about 100 yards. At a point about half a mile from the farmhouse, a mass of volcanic agglomerate rises in the bed of the stream and on both banks. Under the microscope, the rock (No. 7159) "appears to be mainly composed of fragments of a biotite-andesite, consisting of large phenocrysts of oligoclase and plates of altered biotite in a very finely crystalline matrix. One or two fairly large apatites occur having also the appearance of phenocrysts." Greywackes and shales like those at Duntercleuch, seen close to the agglomerate, continue down stream for about 330 yards. About 600 yards from nether Whitecleuch Farmhouse the grey cherts are exposed, and are brecciated along their contact with the grits, so that the junction line may be a fault. Further down the stream black shales alternate with green mudstones, followed by fireclay-looking shales much shattered, and these by flaggy black shales, yielding the following graptolites in good preservation:

Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Dicellograptus sextans (Hall.)
Climacograptus Schärenbergi (Lapw.)

These strata are succeeded by the usual greywackes and shales, which dip S.S.E. in isoclinal folds.

Snar Water (Lower Section).—This stream above Gott, about two miles S.S.W. of Crawfordjohn, has exposed three anticlines of the cherts, with black shales and fireclays occupying the synclines. In the second syncline, on the left bank, in well-bedded black shales, with greenish mudstones, the following graptolites were obtained:

Cœnograptus gracilis (Hall.)
Didymograptus sp.
Cryptograptus tricornis (Carr.)
Dicellograptus patulosus (Lapw.)
,, *sextans* (Hall.)
Diplograptus foliaceus (Murch.)
Climacograptus Schärenbergi (Lapw.)
Dendrograptus sp.
Acrothele sp.

On the north side the Permian breccia rests on the cherts; on the south side, the black shales on the left bank form the southern limb of the third arch, while the greywackes occur on the right bank. In the wood of the Old Castle of Snar, brown decomposing pebbly grits like the Duntercleuch grit are found. At a point about 400 yards above the Castle an arch of grey cherts is succeeded by black shales on the north side only, while

on the south side there is a breccia made up of very small fragments of chert. A short distance up stream, along the strike, at a bend in the burn, brown-weathering grit appears which closely resembles the Duntercleuch grit.

The Snar Water upwards for about a mile flows over a constant repetition of grits like the Duntercleuch beds. The same rocks are seen also in a tributary which joins the Snar from the west, at the bend in its course. This brown grit with clayey shales is also exposed in a tributary that drains the north slope of the Windy Dod to the Snar.

Glentewing Burn (Duneaton Water, south of Crawfordjohn).—The black shales and cherts reappear in this stream on three separate anticlines between the farmhouse of Glentewing and Cleuch. The most northerly exposure, which is about 300 yards up stream, shows radiolarian cherts in the centre, followed on the north side by black shales and an ashy grit with black shale galls. The southern limb is not exposed owing to a covering of drift. About 100 yards higher up fragments of volcanic rock are met with, but the material was not here observed *in situ;* but a few yards further south, where a stone fence reaches the burn, black shales occur, yielding *Didymograptus superstes*, &c. Still higher in the valley, large masses of coarse volcanic agglomerate are found, in such abundance as to suggest that it may be in place underneath. Southwards, in a little side rivulet, near Cleuch Farmhouse, the black shales rise on another fold, and near the head of this streamlet they are associated with volcanic agglomerate like that described as occurring in the Nether Whitecleuch Burn. By means of small exposures on the intervening ridge the agglomerate can be traced E.N.E. across the Mill Scar (1399 feet) to the Glenliscleuch Burn. On the slope of the ridge east of Cleuch Farmhouse, the cherts and black shales occur on three separate folds.

Glenliscleuch Burn (a Tributary of the Shield Burn).—A continuous rock section is exposed in this stream that drains the north-east slope of Mill Scar, from its source to the point of junction with the Shield Burn one mile south-east of Crawfordjohn. In the scars at the head of the cleuch an outcrop of radiolarian cherts and black shales attains a breadth of upwards of 100 yards; the cherts occurring on three separate anticlines. All the strata are much shattered and crushed, and are further altered by much bleaching and decomposition. These folds are succeeded to the north and south by grits; on the north limb, in the midst of the greywackes and grits, masses of agglomerate occur on the top of the bank, which are evidently portions of a similar rock underneath. A specimen from this exposure, when viewed under the microscope, shows "numerous phenocrysts of felspar in a dark, almost black, compact ground mass," and the rock seems to be highly altered hornblende-biotite-andesite, resembling the type of rock in Kiln Burn, Nether Whitecleuch, and in the Shield Burn to be described presently. The Glenliscleuch Burn obliquely traverses the strike of the strata for the

next 350 yards down to a point where it is crossed by a Tertiary dolerite dyke. In this distance it exposes three imperfect folds of cherts, black shales, and overlying greywackes and shales. East of the dyke, the course of the stream almost coincides with the strike of the beds, and for some distance the channel is carved out of black shale, bounded on the south side by an outcrop of radiolarian chert. In the black shales immediately overlying the cherts, the following fossils were obtained: *Didymograptus superstes, Cœnograptus gracilis, C. pertenuis, Dicranograptus zic-zac, D. minimus, Dicellograptus sextans, D. moffatensis, Climacograptus bicornis.* The following assemblage was found in the bands in the north bank: *Climacograptus caudatus, C. bicornis, Dicellograptus caduceus, D. elegans, Diplograptus foliaceus, Corynoides calycularis.*

The black shales here obviously lie in a synclinal fold, as the radiolarian cherts reappear on the north limb of the trough at the foot of the Glenliscleuch Burn.

In the Shield Burn, above its junction with the last-named stream, the first visible strata consist of radiolarian cherts, and within a short distance volcanic rocks appear. The latter are again succeeded by cherts, in the heart of which a small arch of fine-grained diabase-lava appears, with the usual pillowy structure. Southwards these cherts are followed by black shales and pebbly grits. In the midst of the coarser sediments a bed of altered andesite occurs, which, when examined with the microscope, is found to be crowded with phenocrysts of altered felspar, and contains some altered rock fragments. It is highly probable that this volcanic zone, like those in Nether Whitecleuch Burn and at the head of Glenliscleuch Burn, occurring as they do in grits that overlie the black shale series, may be of Lower Caradoc age. Southwards, grey micaceous shales are met with, followed at intervals by folds of radiolarian cherts and black shales.

Fossiliferous (Caradoc) Conglomerate of Duntercleuch and Glendowran, Lead Hills.

Having described the various black shale bands in the Lead-hills district between Abington and Sanquhar, we have now to consider certain pebbly grits and conglomerates, which, at several localities in the same region, are abundantly charged with fossils. Their fossiliferous character was first observed in the course of his original survey of the district by Mr. R. L. Jack, who, from their assemblage of organisms, regarded them as of Caradoc age (Explanation of Sheet 15, p. 14.). In his descriptive account he states that the strata "consists of greywacke passing, on the one hand, into crumbling sandstone, and, on the other hand, into pebbly grits with partings of shale resembling that of the Lowther (shales) series, and with beds of conglomerate which are chiefly found at the base of the

group." Among the pebbles, white vein quartz is by far the most prominent constituent, but fragments of greywacke, black and grey shale, chert, and fragments of volcanic rocks also occur. The two chief localities from which fossils have been obtained are (1) the Back Burn west of Duntercleuch Rig—one of the minor tributaries of the Wanlock Water; (2) the Snar Water south of Snarhead. A third locality lies still further to the north-east on Glendowran Hill. Though organic remains are scattered through the matrix, they occur chiefly in brown decomposing calcareous nodules, which are evidently not derivative. As has been shown in the foregoing pages, these fossiliferous bands lie in rapid synclinal folds of the Arenig volcanic rocks, radiolarian cherts, and overlying black shales. In the Back Burn (page 292) and in the Duntercleuch Burn (page 292) nearly all the graptolites characteristic of the Glenkiln group are found in these shales close to the Caradoc strata. In this region the Moffat type of the Hartfell black shales has largely disappeared, and some Hartfell graptolites; as, for example, *Climacograptus caudatus*, *Dicellograptus elegans*, *D. caduceus*, &c., occur in brown sandy shales (p. 313) overlying the radiolarian cherts and Glenkiln black shales (see Glenrae Burn, p. 320).

After the publication of the list of organic remains from the Duntercleuch conglomerate in the Explanation of Sheet 15, the brachiopoda from this horizon, in the Geological Survey Collection, were examined by the late Mr. Davidson, who regarded them as of Caradoc age. The subjoined list gives the assemblage of organisms which have been obtained from the various exposures of this conglomerate in the Leadhills district:

Nidulites favus (Salt.)
Alveolites sp.
Favosites asper (D'Orb.)
,, sp.
Monticulipora lens (M'Coy.)
Petraia bina (Lonsd.)
,, *elongata* (Phil.)
,, *uniserialis* (M'Coy.)
Stenopora (Favosites) fibrosa (Goldf.)
Glyptocrinus basalis (M'Coy.)
Crinoid stems.
Serpulites sp.
Calymene sp.
Cheirurus sp.
Homanolotus sp.
Ogygia sp.
Phacops caudatus (Brünn.)
Trinucleus fimbriatus (Murch.)
Fenestella sp.
Ptilodictya dichotoma (Portl.)
Leptæna sericea (Sow.)
,, ,, var. *rhombica* (M'Coy.)
,, *(Christiania) tenuicincta* (M'Coy.)
Orthis (Platystrophia) biforata (Schl.
,, *calligramma* (Dalm.)
,, *crispa* (M'Coy.)
,, *polygramma*, var. *pentlandica* (Dav.)
,, *(Dalmanella) testudinaria* (Dalm.)
Rhynchonella Jacki (Dav.)
Strophomena arenacea (Salt.)
,, *corrugatella* (Dav.)
Ctenodonta sp.
Modiolopsis sp.
Bellerophon acutus (Sow.)
,, *trilobatus* (Sow.)
Cyclonema sp.
Euomphalus sp.
Holopella sp.
Murchisonia sp.
Pleurotomaria (Raphistoma) elliptica (His.)
,, *lenticularis* (Sow.)
Turbo sp.
Hyolithes sp.
Orthoceras sp.

Representatives of Glenkiln Shales and Associated Sediments, from the Sanquhar Coal-field to the Clyde near Wandel Mill.

Approaching still further north to the margin of the Silurian Tableland between the north-east corner of the Sanquhar coal-field and the river Clyde at Wandel Mill, we discover that the Lower Hartfell black shales have disappeared, and that the characteristic fossils of the Glenkiln group occur in black seams or films in sandy shales and greywackes. The radiolarian cherts, however, are traceable along the margin of the tableland in a great development, closely associated with a prominent band of "Haggis Rock" or conglomerate, which, in certain sections, rests unconformably on the radiolarian cherts.

Glenaylmer Burn (four miles and a half north-west from Sanquhar.—In this burn, above the fault that bounds the Carboniferous basin, grits and greywackes with minute fragments of black shales and cherts are associated with much-jointed dark blue sandy shales. At a point about a quarter of a mile up stream an important section occurs on the north bank and on the slope overlooking the stream, where the green cherts with radiolaria are exposed. In contact with them, and apparently resting unconformably on them, lies a well-marked breccia, the grey matrix of which contains fragments of the grey radiolarian chert, sometimes measuring four by two inches; also fragments of black shale, though most of the pebbles are of greywacke. About 100 yards up the stream, on the same side of the valley, a beautiful light green variety of chert with radiolaria appears at the edge of the alluvium. On the bank the brecciated conglomerate, seen in contact with the chert, is composed chiefly of greywacke pebbles, some measuring nine inches long, with fragments of chert and black shale. The rock merges into a pebbly grit. About 200 feet above the bed of the stream, due north from this last-mentioned exposure, a very coarse conglomerate is visible, its pebbles being well-rounded and consisting chiefly of greywacke and chert lying in a gritty matrix. Some of the included blocks of Arenig igneous rocks measure two feet across. Near the head of this valley, about the Crags, and just below the point where the Glenaylmer Burn is joined by a tributary from the north, graptolites, referred to *Climacograptus* and *Diplograptus*, are found in thin black seams interleaved in blue shales. In the stream, on the south side of the valley near the watershed, blue shales and greywackes are visible; some of the small branching burns have their courses determined by faults.

Beyond the watershed of the Glengap Burn, occasional exposures of conglomerate, gritty greywacke, and yellow clayey shales are met with, in which no fossils have been found. In the lower portion of that stream, where it flows between the High Knypes and Glenguffock Hill, the solid rocks are for the most part buried under alluvium. A short distance below

Blackgannoch the Spango Water is joined on the south side by a tributary—the Reeve Burn—which drains the eastern slope of Glenguffock Hill, and shows along its course the radiolarian cherts coming to the surface along several folds. In places the cherts are immediately succeeded by blue grits, greywackes, and conglomerate. On the hill slope to the east of this stream, there is an excellent display of the red and grey cherts, which when traced towards the north-east, down the slope towards the old drove road, gradually become granulitised as the margin of the granite is approached. Exposures are rare, but the evidence here of contact metamorphism is similar to that found at some distance from the Loch Doon granite. (See Chapter XXVII.) The cherts are also seen on the Meikle Knypes—the hill east of Reeve Burn.

Blackgannoch Cleuch and Glenwhinny Burn.—In the small burns uniting to form the Blackgannoch Cleuch, that joins the Spango Water, one mile below Blackgannoch, sections are laid open of grey clayey shales, which decompose readily and contain worm tracks. In like manner, at the head of Glenwhinny Burn—a tributary of the Blackgannoch Cleuch—similar grey clayey shales weather externally like the Lowther Shales, though in these tributaries of the Spango Water it is probable, if not certain, that they belong to a lower horizon than the Barren Mudstones of Moffat. In these tributaries the shales are indurated, and show evidence of contact alteration by the Spango granite. The metamorphism of the Silurian rocks in the stream and on the hill slopes to the south of that igneous mass, and as far east as Glenwhinny Burn, is noteworthy, though the rocks at the junction are mostly buried under drift. In the Gairland Burn, on the north side of the granite mass, the alteration of the "Haggis Rock" is very pronounced. The included fragments of chert are quite granulitised and the matrix is rendered schistose, brown mica being abundantly developed.

Fingland Burn (Head of Spango Water).—This stream above the point where it is joined by the Glengap Burn, affords an excellent exposure of the radiolarian cherts, which continues at intervals up to a point about 250 yards from the foot of the burn. Greywackes are occasionally enfolded with these cherts. The massive red and green cherts are again displayed at the foot of the Calf Grain, about 700 yards up stream from the foot of the Fingland Burn. On the south side of this fold, dark sandy shales with black shale strains lie, only a few yards from the edge of the cherts (the black shale seams varying in thickness from an inch to a tenth of an inch). These black seams yielded the following characteristic Glenkiln fossils:

Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Thamnograptus typus (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Climacograptus Schärenbergi (Lapw.)
Brachiopod.

The arch of cherts just referred to can be traced north-east to the slope on the north side of the valley. Towards the south-west the red cherts can be followed by means of small outcrops along the crest of the High Knypes and Kirkland Hills. On the south-west slope of the latter they rapidly "nose out" and are succeeded by greywackes and shales. In a little dry gully on the west slope of the Kirkland Hill, about half a mile to the south of the fault between the Silurian and Old Red Sandstone formations and about 300 yards east from that which bounds the Carboniferous basin of Sanquhar, a peculiar igneous rock is exposed for a distance of 150 yards. The rock resembles a lamprophyre. On the south side of the gully, greywackes and shales are visible, and at the head of the gully the red cherts are seen.

Duneaton Water.—On the west slope of the ridge, at Stonehill, three miles S.W. of Crawfordjohn, grey and red cherts are exposed, which contain abundant radiolaria, and are repeated by sharp folds. Some of the bands are hardened, probably by underlying granite. Black shale bands have not been observed anywhere on this hill, but they are visible in an isolated exposure at the bend of the Duneaton Water at Craighouse, and are there interleaved with grey shales, like those in the Fingland Burn just described, and at Craiglure, near Loch Doon. On the south side of the outcrop of the radiolarian cherts on the Stonehill ridge, a band of fine conglomerate, which can be traced along the ridge, contains pieces of grey radiolarian chert, sometimes an inch across, likewise fragments of black shale and some igneous rocks. On the north side, however, this conglomerate assumes the characteristic type of the well-known "Haggis Rock." It includes abundant minute fragments of various igneous rocks of the volcanic series, with red and grey chert and black shales. The strata on this hill are isoclinally folded, and dip to the south-east at angles varying from 60° to 70°.

In a little burn west of Stonehill, the grey, green, and red cherts, together with the "Haggis Rock," are repeated by folds. Along the line of strike, quarries have been opened in the radiolarian cherts at the Stonehill Farmhouse; red mudstones, which occasionally contain bands of tuff, are there associated with red cherts. On the southern slope of Mountherrick Hill, the fine conglomerate has yielded fragments of *Glyptocrinus* and *Petraia*. At the village of Crawfordjohn, the red mudstones and cherts may be seen by the roadside.

River Clyde near Wandel Mill.—In the Clyde, at the bridge about half a mile above Wandel Mill, a continuous rock section is laid open on the right bank of the stream, where blue grits, weathering with a rusty brown tint, occur in association with blue platy shales which alternate with leaf-like blue-black fossiliferous seams (about an eighth of an inch thick). One layer, about nine yards north of the bridge, yielded the following typical assemblage of Glenkiln fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *explanatus* (Lapw.)
,, *surcularis* (Hall.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)
Climacograptus Schärenbergi (Lapw.)
,, *cœlatus* var. *antiquus* (Lapw.)
,, *bicornis* (Hall.)
,, *tridentatus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *Forchhammeri* (Gein.)
,, *moffatensis* (Carr.)
Leptograptus flaccidus (Hall.)
Dicranograptus ramosus (Hall.)

Again, in Duneaton Water, about three-quarters of a mile above the junction of that stream with the Clyde, south-west of the Middencots Farmhouse, shattered and corrugated shales and greywackes, form a gentle anticline. Fossils are more difficult to obtain at this locality in the dark seams, but the following were collected: *Cœnograptus pertenuis*, *Dicellograptus sextans*, *Diplograptus foliaceus*, *Climacograptus*. Though the strata are repeated by folds, their prevalent dip is towards the south-east. Here the greywackes, shales, and dark seams yielding Glenkiln (Upper Llandeilo) graptolites rest on the radiolarian cherts.

Black Shale Bands in the Basins of the Elvan and Menock Waters and in the Tributaries of the Nith near Kirkbride.

In this belt of ground between the Clyde and the Nith, various folds of the Moffat series reveal in some instances the Arenig lava, the radiolarian cherts, and the Glenkiln-Hartfell bands of black shales in the midst of sandy shales and other sediments. Some of these outcrops of the Moffat series come to the surface in the midst of the Lowther Shales, which are regarded as the equivalents of the Barren Mudstones of Moffat.

Elvan Water.—About a mile to the south-east of Leadhills, in the Windygate Burn, a tributary of the Shortcleuch Water, twisted black shales appear in the midst of greywackes and shales, from which the following graptolites were collected: *Climacograptus caudatus*, *C. bicornis*, *Cryptograptus tricornis*, *Diplograptus foliaceus*, *Dicranograptus ramosus*, *Corynoides calycularis*. This band is prolonged north-eastwards into the Lead Burn, where a core of radiolarian chert appears in the midst of the black shales, the latter being cleaved and yielding fossils sparingly. Several Lower Hartfell fossils were, however, obtained from this locality. In the strike of these exposures near the head of Lead Burn in a north-east direction, a small outcrop of cherts and black shales appears on the north-west slope of Lousie Wood Law, not far from the band of conglomerate on that hill, to which we shall presently refer. Other folds displaying the cherts and black shales are met with in a tributary of the Shortcleuch Burn immediately to the west of Leadburn Rig.

Menock Water (Two Miles South of Wanlockhead).—In the basin of the Menock Water, about two miles south of Wan-

lockhead, several arches of the Arenig Rocks and overlying black shales make their appearance. In one of these the volcanic rocks occur in the core of the fold, followed in regular order by the cherts and black shales. The rocks as a whole have undergone deformation, the cherts in particular showing fine flaser-structure, like the cherts and jasper bands in the neighbourhood of the North Esk, Forfarshire. The arch referred to occurs on the north side of the valley, where the high road crosses a small tributary of the Menock that drains the hill called Middle Moor. At the point where a bridge spans the stream, black shales, much cleaved, dip to the north-west at angles from 45° to 65°. A felstone dyke crosses the burn above the bridge. The black shales have a peculiar sheen or glistening surface, and yield indeterminable traces of graptolites. Further up, cherts with fine flaser-structure succeed, followed by black shales, grey shales, and greywackes. About 200 yards to the east-north-east of this point, along the line of strike, coarse ophitic dolerite or gabbro appears, an intrusive rock of Arenig age; while a few yards further east, the pillowy lava reaches the surface. Both types of rock are cleaved and markedly schistose; thus resembling some of the schistose chloritic igneous rocks in the North Esk region above alluded to. At one point the band of igneous rocks in the core of the fold is 100 feet broad.

The cherts occur on both sides of the fold, and are so well cleaved or schistose, that it is difficult to obtain specimens of radiolaria from them. The black shales occur on the north side of the arch, but on the south side are concealed by vegetation. This fold is traceable for a third of a mile along the north side of the valley, and rapidly noses out towards the north-east; but towards the south-west black shales occur in the Menock Water much in the same line of strike. Again, on the south of the arch of volcanic rocks, black shales are found in the Menock Water below the junction with the Green Carli. From this point upwards, black shales and cherts appear on several folds.

Below the spot where the Whitestone Cleuch joins the Menock half a mile east of Middle Moor, several repetitions of the black shales may be observed, and at one point, about 200 yards below the junction, the lava is seen, truncated by a fault on the east side which brings it in contact with greywackes. In the Whitestone Cleuch, beyond some greywackes and shales in which black shales occur, a fine exposure of cleaved cherts and black shales has been laid open in the stream which runs E.N.E. across the Meikle Arthur Grain towards the county boundary. Southwestwards this fold can be followed for half a mile along the slope on the south side of the valley to a small scar draining into the Menock, at the head of which, volcanic rock is associated with the cherts.

More or less parallel with this arch, and to the south of it, three separate bands of the radiolarian cherts and black shales may be traced, the highest reaching the 1750-feet contour-line. The strata, especially the cherts, are much deformed, so as to

show fine flaser-structure; indeed, at some points the cherts have been sheared into paper-schists.

In the Horseman's Burn, which joins the Menock from the south one mile north of Glenim, several repetitions of the black shales are to be seen, sometimes associated with the cherts. They occur also by the side of the Dempter Road leading to Glenim.

In the Glenimshaw Burn below Glenim, and at the junction with the Long Cleuch, black shales and cherts appear. They have been reddened by infiltration of iron oxide from the Permian rocks that formerly extended over the area. The limit of the stained rocks is well defined; the staining is not observable north of the foot of the Long Cleuch nor to the north of Glenim.

Kirkbride (East of Nith).—To the east of the Nith near Kirkbride, about five miles S.E. from Sanquhar, black shales are frequently exposed, sometimes in the line of strike of the Burnmouth, Cairn Burn, and Chanlock bands, to be described in the sequel. The most prominent outcrops—though, owing to the crushed and dislocated character of the shales, fossils are very difficult to find—are to be met with in the Stroquhairn Burn—a tributary of the Ha' Cleuch—and in one of its branches, the March Cleuch. In both of these sections the cherts appear with the black shales, the former being much crushed, though radiolaria can still be found in them. In these sections the beds are too shattered to yield graptolites. Several felsite dykes occur, and one dyke in particular deserves special mention. It occurs in the Stroquhairn Burn, about 200 yards above the junction with the March Syke, and consists of a purple diabase or melaphyre, closely resembling the lavas of the Permian basin of Thornhill. Here it appears as a dyke which runs east and west, piercing the greywackes on the north side of it and a yellow felsite dyke on the south side.

Crossing the grassy ridge between the head of the Stroquhairn Burn and the head of the Ha' Cleuch, we find the black shales in the latter stream. From one of the less crushed layers the following fossils were obtained: *Leptograptus flaccidus*, *Dicellograptus Forchhammeri*, *Diplograptus foliaceus*, and *Corynoides calycularis*. There can be little doubt that this layer represents one of the bands of the Lower Hartfell black shales. The cherts do not appear at the head of the Ha' Cleuch, but they are exposed on the surface on the moor to the north-east of the burn, and can be traced to the head of the Old March Cleuch, a tributary of the Enterkin Burn, where they are well displayed though much stained with the former cover of Permian or Carboniferous strata. They occur here in association with bleached black shales. In places the cherts are hardly recognisable as such, and the black shales might easily escape notice owing to the staining. The cherts appear again in streamlets at the foot of the Auchenlone Burn, near the northern limit of the Permian basin.

Though fossils were not obtained from the black shales in the tributary of the Ha' Cleuch north of Kirkbride, yet it is clear

from the presence of the radiolarian cherts and the dark flinty ribs that the Glenkiln black shales are there represented. The Lower Hartfell black shales probably occur, though this horizon has not been proved by fossils. To the south of the exposure of black shales in the Stroquhairn Burn, dark blue shales appear which might yield fossils.

Lime Cleuch, Cairn Hill.—About half a mile to the north-west of Kirkbride, at the very head of the Lime Cleuch, above the 1000-feet level, and not far from the top of the Cairn Hill, black shales are exposed in a rocky gully which runs north-east and south-west, or nearly parallel to the strike of the beds. In this section both the Glenkiln and Hartfell black shales are represented. The black shales yield *Diplograptus foliaceus*, *Dicellograptus*, *Cryptograptus tricornis*, and *Lasiograptus margaritatus*. About 150 yards above the fork, on the right bank, platy black shales appear with seams of grey clays, and yield the following fossils:

Dicellograptus Forchhammeri (Gein.)
Lasiograptus margaritatus (Lapw.)
Retiolites (Neurograptus) fibratus (Lapw.)
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)
Corynoides calycularis (Nich.)
Glossograptus Hincksi (Hopk.)

The distribution of the organisms here is noteworthy. One layer is crowded with *Corynoides calycularis*, another with *Dicellograptus*, another with *Diplograptus foliaceus* in fine preservation. This is the continuation of the Lower Hartfell band found at the fork. A few yards up the gully, on the left bank, at the base of the cliff, in black shales dipping towards the south-east, the following forms of characteristic Glenkiln type were obtained:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Climacograptus cœlatus var. *antiquus* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* var. *B.* (Lapw.)
,, *moffatensis* (Carr.)
Cryptograptus tricornis (Carr.)

Grey fireclays are interleaved in these Glenkiln black shales, and thin black siliceous ribs are also associated with them. Another notable feature of this section is the presence of lenticles and patches of greywacke in the black shales.

Still further north, black shales appear on isoclinal folds stretching from Glenim towards the Nith south of Dalpedder. In general they are too much crushed to yield recognisable species of fossils. A band appears also in the Auchenlone Burn, about a mile above its junction with the Enterkin. To the south of a line drawn from the mouth of the Auchenlone Burn to Glenim, the beds (greywackes and shales, cherts, and black shales) are much stained.

Immediately to the north of the line which has provisionally been drawn as the northern base-line of the Llandovery Rocks

of the Central Belt, a prominent group of shales typically developed in the Lowther Hills is traceable from the Clyde at Elvanfoot to the Nith above Enterkinfoot. It consists of finely laminated shales with flaggy greywackes and occasional grits or conglomerates. The shales weather with a brown or buff colour, with an occasional spotted appearance. The apparent synclinal arrangement of this shaly series in the Lowther Hills is quite misleading, because, as we have already shown, the Arenig cherts and Glenkiln-Hartfell black shales repeatedly come to the surface in the midst of the overlying Lowther group in the basin of the Elvan Water and between the Menock Water and Enterkinfoot. Various bands of pebbly grit and conglomerate appear in this series, of which the one on the north-western slope of Lousie Wood Law, two miles south-west of Elvanfoot, is perhaps the most conspicuous. It contains well-rounded pebbles of grit, greywacke, pieces of hardened shale, Lydian-stone, and quartz embedded in a matrix of greenish grey quartzose grit.

CHAPTER XVI.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC FORMATIONS BETWEEN NITHSDALE AND LOCH DOON.

i. Black Shale Bands between Burnmouth, Nithsdale, and Dalshangan, North of Dalry.

ALONG the axial line that extends from Burnmouth on the river Nith (four miles S.E. of Sanquhar) to Dalshangan near the junction of the Deugh with the river Ken (five miles north from St. John's Town of Dalry)—a distance of 17 miles—the Moffat series is well developed. In certain sections it yields characteristic Glenkiln graptolites and forms belonging to the two lower zones of the Hartfell black shales. In some of the anticlines, again, the Arenig cherts are well represented, while in the Nith section at Burnmouth and in the Linn Burn, south-west of Fardingmullach (Sheet 15 of the Survey Map), small exposures of volcanic rocks make their appearance. Though prominent outcrops of the Moffat series can be traced along this line, it must be borne in mind that they are not prolongations of one and the same band. The outcrop at Dalshangan, for example, lies to the south of that of Shinnelhead.

River Nith at Burnmouth.—In the Nith, opposite Ardoch Farmhouse, four miles south-east of Sanquhar, the following arrangement of the strata is visible in the river. On the right bank above the bend, nearly south-west from Ardoch Farmhouse, shattered and crushed black shales are followed on the north side by dark blue shales, and on the south by grey and red cherts. A few yards further down, a fault brings the Glenkiln black shales against the cherts and a small mass of igneous rock like one of the types of Arenig lava. To all appearance the cherts here form the core of an arch with a small exposure of Arenig lava, truncated on the south side by a fault. From the black shales near this fault the fossils given in the subjoined list were collected, which are characteristic of the Glenkiln group. None of the Lower Hartfell forms found in the Cairn Burn, to be referred to presently, was obtained from this locality, but the black shales are too much crushed to permit of examination close to the overlying shales and conglomerates:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus zic-zac (Lapw.)
,, *ramosus* (Hall.)
Diplograptus foliaceus (Murch.)
,, *mucronatus* (Hall.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Glossograptus Hincksi (Hopk.)
Dicellograptus moffatensis (Carr.)
A brachiopod.

Southwards this outcrop of black shales is followed by another arch of the radiolarian cherts, with the black shales on the south side. Here a blank interrupts the section for a short distance, when grey and blue shales with scattered pebbles, merging into a bed of conglomerate, appear. This conglomerate has a shaly and gritty matrix, in which pebbles of white quartz and pieces of black shale occur, with occasional rounded pebbles of greywacke. It is followed by crushed and dislocated black shales, forming a small exposure. Lower down the river, greywackes and blue shales with conglomeratic bands appear. At this point dark blue shales alongside of the conglomeratic bands have furnished a *Climacograptus*, probably *C. caudatus*. Still further down, beyond some greywackes and shales, another conglomeratic band is seen, with pebbles, either of quartzite or altered greywacke and quartz-felsite. The greywackes here have a baked appearance, possibly altered by an intrusive felsite dyke.

Burnsands Burn.—To the south of the axial fold referred to above, grey and blue shales are well seen in a cutting by the road-side about half a mile south of Burnmouth, and also in the Burnsands Burn above Crairieknowe. In this series of shales a remarkable conglomerate is typically displayed in the last-named stream, about half a mile above Crairieknowe. The rock is variable in character. In places it is a pebbly grit with small white quartz pebbles; sometimes it contains sub-angular pieces of black shale with graptolites, lying either along or across the bedding planes. Rounded nodules of grey limestone and pebbles of greywacke, grit, quartzite, and one or two pebbles of a banded rock like a quartzose gneiss, also occur. Some of the larger pebbles vary from six inches to a foot across. From the black shale fragments the following fossils were obtained: *Cœnograptus*, *Dicellograptus sextans*, *Diplograptus foliaceus*, and *Corynoides*. No fossils were observed in the limestone nodules. This conglomerate furnishes additional evidence of the local elevation and erosion of the Glenkiln black shales and other Silurian sediments.

Fardingmullach.—In a streamlet that drains into the Burnsands Burn from the south, about 400 yards east of Fardingmullach shepherd's house, an excellent section shows the relation of the radiolarian cherts to the Glenkiln black shales, on a rocky scar at the head of the burn (Figures 78 and 79). The cherts and black shales occur on the east side of the burn. The black shales form the lower portion of the scar on the northern limb of the anticline, while the radiolarian cherts are prominently developed near the top of the scar, in the core of the arch

(C. Fig. 78). The black shales are disposed in sharp synclinal folds of the cherts, and appear likewise on the south-east limb of the fold (2^{I}, 3^{II}, Fig. 79). The grey and red mudstones are exposed in the centre of the fold, the grey and green cherts predominating. The best fossiliferous localities for graptolites are to be found on the northern limb of the fold, where the outcrop of black shales facing the burn is about 40 feet broad. The lower portion of the band is composed of thin black siliceous bands with thin seams of sooty shales containing graptolites.

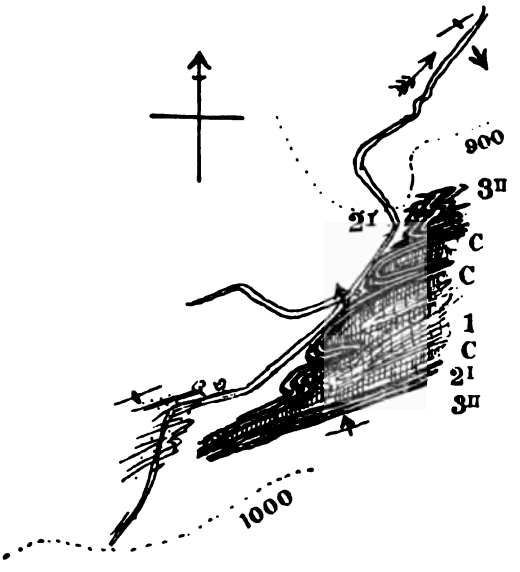


FIG. 78.—Plan of Strata in a tributary of Burnsands Burn, 400 yards east of Fardingmullach, Nithsdale.

1. Red mudstone (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc).

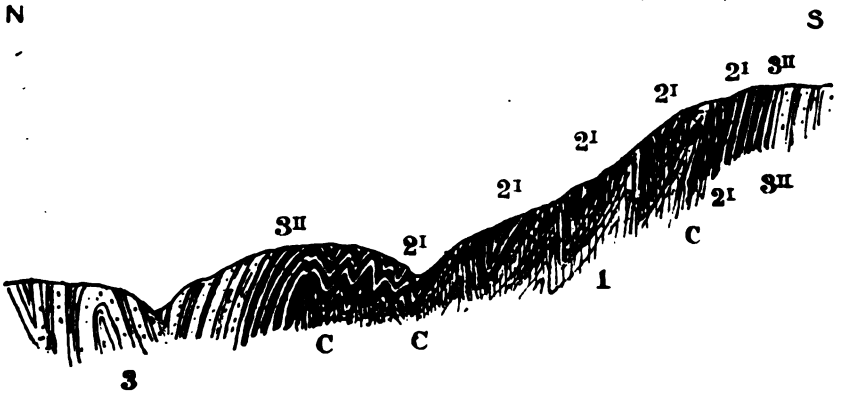


FIG. 79.—Section, tributary of Burnsands Burn, 400 yards east of Fardingmullach, Nithsdale.

(Explanation as in Fig. 78.)

The following species, among others, were obtained from the Glenkiln horizon: *Didymograptus superstes*, *Cœnograptus*, *Lasiograptus bimucronatus*, *Diplograptus foliaceus*, and *Dicellograptus*.

These strata are succeeded by black shales yielding *Dicranograptus ramosus*, *Climacograptus bicornis*, *C. caudatus*, *Diplograptus foliaceus*, and *Acrotreta Nicholsoni*. Some of the thin seams are crowded with this brachiopod, and also with *Climacograptus*. In addition to these fossils, the same shales contain *Corynoides calycularis*, and *Dicellograptus elegans*, while in some seams *Climacograptus caudatus* is abundant, in others *C. bicornis*. Blue and grey shales emerge on the grassy slope on the other side of the hollow, but the sequence upwards to these shales is not visible. The general dip in this section being to the north-west, the strata are thus disposed in a series of isoclinal folds (Fig. 79).

About half a mile to the north-east of the section just described, the Lawyers Cleuch—a tributary of the Burnsands Burn from the north—displays crushed and shattered black shales, bounded on both sides by shales with scattered pebbles, like the beds at Burnmouth on the Nith.

About a mile to the south-west of Fardingmullach, in the Druidhill Burn, in the line of strike of the folds already described, an axial fold of cherts brings up black shales on both sides. The black shales reappear in the Linn Burn—a tributary of the Druidhill Burn—but in both streams the strata are much shattered and crushed, and fossils were not obtained from them. At a point about a third of a mile above the junction of the streams, decomposing green diabase-lava occurs in the Linn, in contact with black shales. Though much crushed and veined with carbonate of lime, the rock exhibits the pillowy structure at one point.

Cairn Burn.—This stream which drains the northern slope of the Cairnkinna Hill (1813 feet), affords a section of black shales near the fork, and for some distance below that point. At the foot of the north branch, platy black shales have yielded *Dicellograptus Forchhammeri* (seen in countless profusion on the slabs); and *Diplograptus foliaceus*, &c., beautifully preserved. *Glossograptus Hincksi* and *Climacograptus* have also been found. A few yards up this branch, at the foot of the waterfall, a fault crosses the burn, and brings grey shales and greywackes against the black shales.

The most important fossiliferous locality, however, lies about 60 yards below the fork, on the north bank of the stream, where platy shales dip about 70° to S.S.E. In a thickness of about twelve inches of these strata the following fossils were collected:

Dicellograptus Forchhammeri (Gein.)
" *caduceus* (Lapw.)
" *elegans* (Carr.)
Dicranograptus ramosus (Hall.)
Leptograptus flaccidus (Hall.)
Climacograptus bicornis (Hall.)
" *caudatus* (Lapw.)
Amphigraptus radiatus (Lapw.)
Glossograptus Hincksi (Hopk.)
Diplograptus foliaceus (Murch.)
Lasiograptus margaritatus (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)
Siphonotreta micula (M'Coy.)

The presence of *Climacograptus caudatus* and *C. caduceus* defines the horizon of this band which underlies the *Pleurograptus linearis* zone, and belongs to the middle zone of the Lower Hartfell black shales. Certain interesting features connected with the mode of occurrence of some of these graptolites deserve notice. For example, some of the slabs are crowded with *Dicellograptus Forchhammeri*, others with *Leptograptus flaccidus*, others again with *Diplograptus foliaceus*. Apart from the presence of the special zonal forms, the occurrence of these species in such profusion is a feature peculiar to the lower Hartfell zones.

In the Carlinstane Burn which joins the Scar Water about a mile below Glenmanno, black shales occur, very much crushed. They reappear in the Hallscar Cleuch, probably in the same line of strike.

Scar Water.—Further north, in the Scar Water, at the bridge across the stream leading to Glenmanno, platy black shales dip to the south-east at high angles. A few feet south of the bridge they have supplied *Diplograptus foliaceus* in profusion on a single slab to the exclusion of other forms. Specimens of *Lasiograptus margaritatus* and siculæ of *Diplograpti* have also been obtained. Under the bridge greywackes and shales crop out.

Hall Burn.—The band of black shale in the Scar Water, at the Glenmanno Bridge, is represented in several arches in the Hall Burn.

Tributary of the Dalzean Burn (South-West of Glenmanno).—South-westwards from the Scar Water a tributary of the Dalzean Burn, which rises on the slope of Craigbuie Hill, displays a section of the radiolarian cherts and black shales. A fault runs up the bed of the stream, bringing greywackes and shales in contact with the cherts and black shales. In addition to the Glenkiln black shales with thin dark flinty ribs, some layers are crowded with *Diplograptus foliaceus* and *Corynoides calycularis*. It is probable, therefore, that the lower zones of the Hartfell black shales are also represented in this section.

Chanlock Water.—A section of the radiolarian cherts with black shales has been laid open at the top of the Peathouse

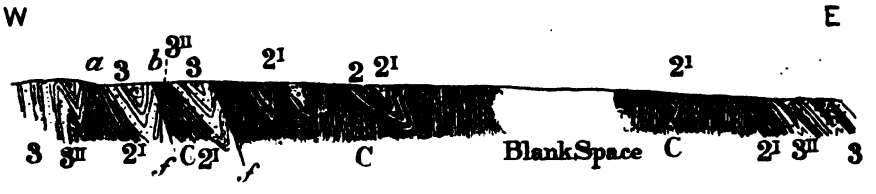


FIG. 80.—Section in Chanlock Water, Chanlockhead.
C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales.
3. Greywacke and shale (Caradoc).

Cleuch, a small tributary of the Chanlock Water above Chanlockhead. About half a mile west from Chanlockhead shepherd's house, the most westerly exposure of black shales occurs, and

from this downwards for a distance of 500 yards the stream flows over black shales with radiolarian cherts and greywackes. In the foregoing section (Fig. 80) the most westerly fold is represented by *a*. At locality *b* another fold shows the black shales. On the west side of this arch a small fault brings the graptolite shales in contact with the greywackes. A few feet from this fault these platy shales contain well-preserved graptolites belonging to the Lower Hartfell zones, as given in the following list:

Dicellograptus moffatensis (Carr.)
,, sp.
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

At this locality some of the slabs are crowded with *Dicellograptus*, as is the case with the same zone in the Cairn Burn and at intermediate localities.

Lower down the stream the radiolarian cherts occur in compound folds with the black shales (C, 2^1, Fig. 80). After a blank in the section the black shales reappear in the stream near a footbridge about 500 yards west from Chanlockhead shepherd's house. In this case also they are associated with radiolarian cherts which form the core of the arch. A few yards above the footbridge they afforded the following typical Glenkiln forms:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
Dicranograptus formosus (Hopk.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)

Black shales appear in the Chanlock still further down, opposite the shepherd's house of Chanlockhead.

Shinnelhead (Sheet 9 of Survey Map).—In the basin of the Shinnel Water, an interesting section of the Arenig cherts and black shales is to be seen in Patie Cleuch, about 300 yards west of Shinnelhead shepherd's house. In this stream the grey Arenig cherts with radiolaria are brought to the surface along several axial folds, followed by the Glenkiln-Hartfell black shales. The following fossils were obtained from the exposures of the Glenkiln shales in this section:

Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *tridentatus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Dicranograptus ramosus (Hall.)

From the Hartfell black shales the following assemblage was collected:

Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Dicellograptus caduceus (Lapw.)
Diplograptus foliaceus (Murch.)
Lasiograptus margaritatus (Lapw.)
Glossograptus Hincksi (Hopk.)
Corynoides calycularis (Nich.)
Retiolites in large numbers, but indistinct.
Acrotreta Nicholsoni (Dav.)

At the highest exposure of black shales in Patie Cleuch, which is about 400 yards up stream from the Shinnel Water, the black shales of the Hartfell group yielded *Dicellograptus Forchhammeri*, *D. moffatensis*, *Diplograptus foliaceus*, and *Leptograptus flaccidus*.

In a small streamlet that joins the Shinnel Water on the south side of the valley near Shinnelhead shepherd's house, some axial folds reveal the grey radiolarian cherts and black shales. The latter are so crushed that fossils are difficult to obtain from them, but the following among other forms were here collected: *Lasiograptus bimucronatus*, *D. foliaceus*. *D. tricornis*, *Dicellograptus*, *Corynoides calycularis*.

South-westwards along the strike of the Shinnelhead band, the cherts and black shales reappear in the Appin Burn, about a mile from the head of the stream. About 150 yards north of a small tributary from the Conrick Hass, at the northern margin of an alluvial patch, Glenkiln shales with black cherty ribs and seams of black shales have yielded an assemblage of characteristic fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Thamnograptus scoticus (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus margaritatus (Lapw.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, sp.
Dicranograptus zic-zac (Lapw.)
,, *ramosus* (Hall.)
,, *Nicholsoni* (Hopk.)
,, *formosus* (Hopk.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Corynoides calycularis (Nich.)

Further north in the Appin Burn a small exposure of the grey cherts with radiolaria is succeeded on the north side by black shales. At the most northerly point, where the black shales in this section are seen in contact with greywackes, the black bands yielded *Dicranograptus Nicholsoni* (wide-angled variety), *Siphonotreta micula*, and a *Diplograptus* like *D. euglyphus*.

The small tributary of the Appin Burn which drains the south-east slope of Blackcraig Hill exposes black shales that dip south-east at an angle of 80°. They reappear on the col between the Appin and Dalwhat Waters, where in one exposure they yield *Dicranograptus ramosus* and *Diplograptus foliaceus*. They are visible at one point in the Conrick Burn, about half a mile from the Dalwhat Water. Here they pass underneath a covering of boulder-clay and moraine-material to reappear in the Dalwhat Water and Dibbin Lane.

Dibbin Lane and Dalwhat Water.—The sections now to be described are of special interest from the large exposures of the black shale series and the excellent preservation of the fossils at certain localities, and also from the assemblage of graptolites characteristic of part at least of the Hartfell black shales.

The Dalwhat Water, just below the mouth of Dibbin Lane, flows over flaggy shales and grits; above that point black shales

appear, associated with grey cherts that contain abundant radiolaria. On the north side of the axial fold, the thin partings of black shales between the black cherty ribs of the Glenkiln group contain the following fossils:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Dicellograptus moffatensis (Carr.)
Dicranograptus ramosus (Hall.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)

The Dibbin Lane is a narrow pass that leads to the streams draining into the river Ken. Its lower slopes are covered with

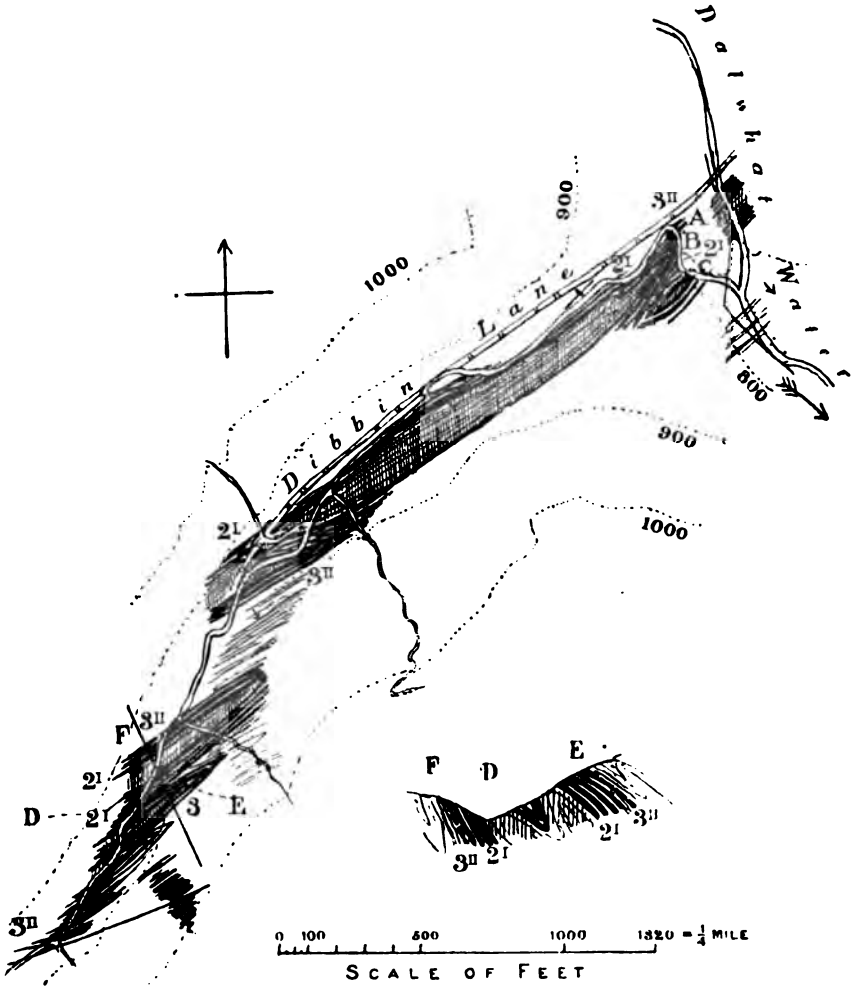


FIG. 81.—Plan and Section of Strata, foot of Dibbin Lane, Dalwhat Water.
C. Radiolarian chert. 2I. Glenkiln Shales. 3II. Lower Hartfell Shales.

drift. At the lower end of the pass the Moffat Shales appear on the south bank and run up the valley, forming a ridge at the outer edge of the alluvium. They are also visible at a bend in the Lane to the north of this ridge, as shown in the accompanying ground plan (Fig 81). On the south side of the stream at C, two small arches of the red radiolarian cherts are overlain by the Glenkiln black shales of the normal Moffat type, viz.: black cherty ribs with thin sooty partings of black shale, containing, among other forms characteristic of this group: *Climacograptus cælatus* var. *antiquus* (Lapw.) *Diplograptus perexcavatus*, and *D. foliaceus*. Representatives of the Hartfell black shales occur on the north limb of this fold at A, in the form of platy shales, yielding the following typical forms, which prove that these shales represent the lower portion of the Hartfell black shale group:

Climacograptus caudatus (Lapw.)
Diplograptus foliaceus (Murch.)
Corynoides calycularis (Nich.)
Dicellograptus Forchhammeri (Gein.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Leptograptus flaccidus (Hall.)

At a point about 120 yards up the stream from the dyke that crosses the mouth of Dibbin Lane, the Glenkiln black shales, as displayed on the face of the bank on the south side of the stream, again present all the lithological characters so typical of this group in the Moffat region. They consist of black cherty ribs with thin partings of black sooty shales, from which a large assemblage of the typical Glenkiln fossils has been obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Lasiograptus bimucronatus (Nich.)
,, *Harknessi* (Nich.)
Diplograptus foliaceus (Murch.)
,, *Whitfieldi* (Hall.)
,, *perexcavatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus formosus (Hopk.)
,, *ramosus* (Hall.)
Dicranograptus minimus (Lapw.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
,, *cælatus* var. *antiquus* (Lapw.)
Dicellograptus patulosus (Lapw.)
,, *divaricatus* (Lapw.)
,, *sextans* (Hall.)
,, *moffatensis* (Carr.)
Leptograptus flaccidus (Hall.)
Glossograptus Hincksi (Hopk.)

Higher up in the Dibbin Lane the cherts appear in greater development. At a point about 600 yards up stream, grey cleaved cherts appear on the south bank associated with red and grey mudstones, which enclose brachiopods. The south limb of this fold of cherts and red mudstones shows the Glenkiln black shales, which are abruptly succeeded by greywackes and shales.

The axial fold of radiolarian cherts and mudstones which extends along the south bank of the Dibbin Lane crosses the stream at a point about half a mile up from the junction with the Dalwhat Water. Here the burn, taking a bend towards the south, crosses the strike of the fold. On the south bank, grits dip south-east near the black shales, and are succeeded by flaggy sandy shales with worm tracks. The latter occupy a synclinal

fold, and are bounded by grits on the south side. These are in turn followed by another axial fold of the Arenig cherts, with the black shales (Glenkiln and Hartfell) on both sides. This arch, forming a prominent ridge of rock, can be traced south-westwards till it crosses the Dibbin Lane to the west of a sheep-fold on the south side of the stream, where two arches of the cherts occur with the Glenkiln black shales in the centre of the syncline and flanking the outer folds of the chert (Fig, 81, Section).

On the north bank of the stream (at D, Fig. 81), the black shales with black cherty ribs in the central fold yielded the following forms:

Didymograptus superstes (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
Climacograptus bicornis (Hall.)
Dicranograptus ramosus (Hall.)

On the southern limb of the fold (at E, Fig. 81), the Hartfell group occurs in the form of platy black shales, which resemble those of a similar horizon in the Cairn Burn (*supra* p. 336), and yield the forms characteristic of the *Climacograptus caudatus* zone. The slabs are crowded with large specimens of *Climacograptus caudatus*, also with *Corynoides calycularis* and *Diplograptus foliaceus* in profusion. On the north side of this compound anticlinal fold (at F, Fig. 81), the black shales yield *Climacograptus caudatus*, *Corynoides calycularis*, *Diplograptus foliaceus*, and *Glossograptus Hincksi*.

The section of this compound anticline shows that the Moffat black shales (Glenkiln-Hartfell), as here represented, still preserve the normal lithological characters of the Moffat region. The highest sub-zones of the Hartfell group, however, have not been detected in this section, and it is probable that they are represented by some of the succeeding sediments.

Still higher up the Dibbin Lane, further axial folds reveal the cherts and Glenkiln-Hartfell black shales, till at a point on the north bank of the stream, about two-thirds of a mile up from the Dalwhat Water, black shales of the Hartfell group merge into black sandy shales with large specimens of *Dicellograptus*, associated with *Diplograptus foliaceus*, *Glossograptus Hincksi*, and *Leptograptus flaccidus*.

About a third of a mile from the county boundary, the hill slope on the south side of the Pass is scarred by several small streams, most of which expose some of the members of the Moffat series. In the second streamlet from the county boundary, draining the west slope of the Martour Hill, flinty black shales occur, and limestone nodules. On the other side of the county boundary, the representatives of the Moffat series can still be traced at intervals in a south-west direction. About a quarter of a mile from the boundary the stream forks, one branch draining the southern slope of Benbrack Hill and the other rising on the mossy col between Dibbin Lane and Manwhill. On the south side of the latter branch, an arch of the radiolarian cherts

throws off the black shales on either side; while in the former branch, the Hartfell black shales are well displayed in contact with the greywackes. Here the strata dip southwards at 56°, and the black shales have furnished the following characteristic assemblage of fossils:

Dicellograptus Forchhammeri (Gein.), in profusion.
Leptograptus, in profusion.
Corynoides ,,
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
Dicranograptus Nicholsoni (Hopk.)
Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)
Siphonotreta micula (M'Coy.)
Retiolites (Neurograptus) fibratus (Lapw.)

Manwhill.—On the north slope of the Stroanfreggan Burn, the black shales appear in a small burn about 350 yards south-west of the shepherd's house, near the road leading to Manwhill. Cleaved black cherts are there seen with the black shales. The latter yielded the following fossils: *Didymograptus superstes, Cryptograptus tricornis, Climacograptus bicornis, Diplograptus foliaceus, Dicellograptus sextans, Dicranograptus ramosus, Glossograptus Hincksi.* The cherts and black shales are likewise met with in a tributary of the Stroanfreggan Burn on the north-west side of the valley, and about half a mile from Manwhill.

Stroanpatrick.—A good section of the Moffat series has been cut by the Long Burn, about a third of a mile north-east of the ruin of Stroanpatrick shepherd's house. Here two arches of the strata are exposed; of these the more southerly arch of grey cherts measures about two feet in breadth, while the distance from this point to the brown flaggy shales is about eight yards. The following fossils were found in the black shales on the south side of this arch of cherts, viz.: *Diplograptus foliaceus, Cryptograptus tricornis, Climacograptus bicornis, C. peltifer*, and *Acrotreta Nicholsoni*, &c. On the north side of the same arch of cherts the black shales yielded:

Didymograptus superstes (Lapw.)
Dicranograptus minimus (Lapw.)
Climacograptus bicornis (Hall.)
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)
Clathrograptus cuneiformis (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

Further up stream shattered Glenkiln Shales can be followed till they rest on the second arch of the cherts, which is from four to six yards across. The black shales on the south side of this fold dip at a low angle, while on the north side they are nearly vertical. At the northern limit of the section the Hartfell black shales contain *Dicellograptus caduceus, D. elegans, Diplograptus foliaceus, Leptograptus flaccidus;* in band next greywacke, *Dicellograptus sextans, Corynoides calycularis*, and *Siphonotreta micula.* Near the ruin of Stroanpatrick shepherd's house a very small exposure of black shales may be seen.

Dalshangan, Water of Deuch.—Proceeding westwards for a distance of nearly four miles to the Water of Deugh, we find an important section of black shales of the Hartfell

group to the north of the mansion house of Dalshangan. About a third of a mile north of Dalshangan the Pulwhanity Burn, about 200 yards above its junction with the Deugh, flows over black shales pierced by intrusive dykes, and associated with greywackes and shales. On the west bank of the Deugh, at a point about 300 yards from the foot of Pulwhanity Burn, fine specimens of *Climacograptus caudatus* have been obtained. The black shales occur on the grassy slope about fifty feet above the level of the Deugh, and are so completely isolated that their relations to the surrounding strata cannot be ascertained. They have supplied the following fossils:

Climacograptus caudatus (Lapw.)
Dicranograptus Nicholsoni (Hopk.)
,, *ramosus* (Hall.)
Diplograptus foliaceus (Murch.)
,, mucronated.
Leptograptus flaccidus (Hall.)
Dicellograptus Forchhammeri (Gein.)
Dicellograptus, numerous arms covering slabs.
Climacograptus bicornis (Hall.)
Retiolites (Neurograptus) fibratus (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

Black shales are again exposed on the banks of the Deugh about 200 yards further to the north-east.

Small outcrops of the Moffat series come to the surface further to the south-west, in certain tributaries of the river Ken, that drain the lofty watershed of the Kells. These sections will now be described.

Pulmaddy Burn.—In this stream, about a mile above its junction with the Water of Deugh (Sheet 8 of the Survey Map), black shales, visible on the left bank near Largerie, and on the hill slope to the north-east, are corrugated and crushed and have supplied no graptolites.

Pulharrow Burn.—In a small tributary of the Pulharrow Burn, about 550 yards W.N.W. of Nether Forrest, near an old fence, a small outcrop of black shales has yielded *Cœnograptus gracilis*, *Diplograptus foliaceus*, *Cryptograptus tricornis*, and *Dicellograptus*. In the Pulharrow Burn, about half a mile to the west of Nether Forrest and north of the Bush Cottage, another outcrop of the Moffat series, though not continuous, is interesting on account of the presence of a thin zone of volcanic rocks which seems to occupy a higher horizon than that of the Arenig series. The following ground-plan shows the disposition of the rocks at this place. At the western limit of this section, on the north bank of the stream, well-bedded platy shales yield *Dicellograpti* in profusion in certain layers, together with the large variety of *Diplograptus foliaceus*. The mode of occurrence of these forms suggests that the strata belong to the Lower Hartfell horizon. Two or three yards below this point, on the north bank, thin grey greywackes and shales occur with black shales, which yield poorly preserved graptolites. Eastwards a band of diabase-lava (Bb2, Fig. 82), about 50 feet broad, weathers spheroidally, but is too much decomposed for microscopic determination, though in the field it bears a close resemblance to some of the fine-grained diabase-lavas of Arenig

age. On the south-east side of the exposure, black shales occur, yielding the zonal Glenkiln form *Dicranograptus minimus*. Again, on the bank of the burn below the footbridge, black shales appear, from which certain typical Glenkiln fossils have been obtained. Further down, the stream lays bare alternations of blue-black shales and thin greywackes and shales. From one

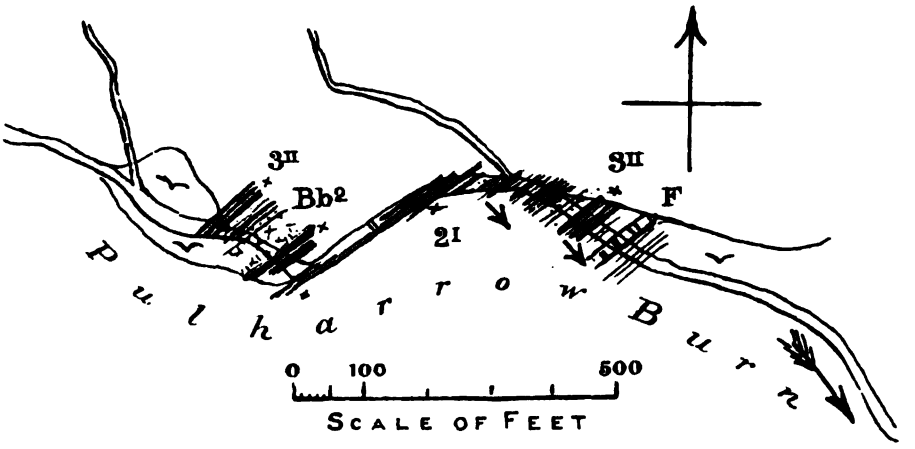


FIG. 82.—Plan of Strata in Pulharrow Burn, near Nether Forrest.

2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. Bb2. Diabase-lava. F. Felsite dyke. ~ Alluvium.

of the black shale bands on the north bank *Climacograptus caudatus* was obtained. From the arrangement of the strata in this section it would seem that the Glenkiln back shales are the lowest beds exposed, and that these are followed on both limbs by black shales and other sediments, from which Lower Hartfell fossils have been collected.

Near Burnhead, south of Nether Forrest, various outcrops of black shales appear, but in places too much altered by the adjacent mass of igneous rock to yield graptolites.

ii. Black Shale Bands between Upper Appin, Shinnel Water, and Arndarroch, River Ken.

Upper Appin (Shinnel Water, Sheet 9 of the Survey Map).—About a mile to the south of the black shale bands already described between Shinnelhead and Dalshangan, many of the outcrops of similar shales do not yield graptolites in such profusion, partly owing to their shattered character and partly to the cleavage of the shales.

In the Appin Burn, about half a mile to the west of Upper

Appin shepherd's house, the black shales, including about two feet of dark greywacke, have yielded the following fossils:

Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *tricornis* (Carr.)
Climacograptus peltifer (Lapw.)
,, *bicornis* (Hall.)
,, *Schärenbergi* (Lapw.)
Glossograptus Hincksi (Hopk.)
Dicranograptus zic-zac (Lapw.)
,, *ramosus* (Hall.)
,, sp.
Corynoides calycularis (Nich.)
,, sp.
Siphonotreta micula (M'Coy.)
Acrotreta Nicholsoni (Dav.)

Another fold of the black shales is seen in the Appin Burn less than a quarter of a mile west of Upper Appin shepherd's house. They are also exposed in a tributary of the Appin Burn from the south, opposite Upper Appin, where they have yielded *Climacograptus caudatus*, *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Acrotreta Nicholsoni*, &c.

Glenjaan Burn, Culmark, Arndarroch.—Further to the south-west, near the head of the Glenjaan Burn, and not far from the county boundary, the radiolarian cherts appear with the Glenkiln-Hartfell black shales. The following fossils, comprising forms characteristic of both groups, were collected from this band:

Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
,, *caudatus* (Lapw.)
Glossograptus Hincksi (Hopk.)
Dicellograptus Morrisi (Hopk.)
Leptograptus flaccidus (Hall.)
Siphonotreta micula (M'Coy.)
Retiolites sp.

On the western side of the county boundary, the prolongation of this band is found in the Carlae Burn, about a mile and a half to the east of Manwhill shepherd's house, where the black shales have yielded the following assemblage of organisms:

Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
,, *mucronatus* (Hall.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Corynoides calycularis (Nich.)
Dicranograptus Nicholsoni (Hopk.)
,, ,, wide-angled variety.
,, *ramosus* (Hall.)
Glossograptus Hincksi (Hopk.)
Leptograptus flaccidus (Hall.)
Acrotreta Nicholsoni (Dav.)

The black shales reappear in the Carroch Lane, north of Culmark, where they are much corrugated, are associated with greywackes and shales, and have yielded *Dicranograptus Nicholsoni* (wide-angled variety), *D. ramosus*, *Climacograptus caudatus*, *Dicellograptus Morrisi*, *D. Forchhammeri*, &c. Still further to the south-west, similar strata are exposed by the roadside near Arndarroch, and in the river Ken near Dundeugh. Near Arndarroch they are associated with grey cherts, and contain *Diplograptus foliaceus*, *Cryptograptus tricornis*, and *Climacograptus bicornis* (wide forks).

iii. Black Shale Bands extending from Corfardine, Scar Water, by Clodderoch and Margree to Gordonston, near Dalry.

Corfardine, Clodderoch, Ballinie, Margree, and Gordonston (Sheet 9 of Survey Map).—Proceeding southwards across the strike of the strata, we have now to describe an important band of flagstones, shales, and mudstones, including certain seams charged with a characteristic assemblage of graptolites which furnish definite palæontological evidence of the age of the series. This band, which is much broader at certain localities than at others owing to the reduplication of the strata, is traceable across Sheet 9 of the Survey Map from Corfardine and Laight on the Scar Water, south-west by the Clodderoch Burn, Craigdarroch, Ballinie, Margree, and Gordonston, north-east of Dalry (river Ken). Although graptolites have been found at various localities along the line of strike of the beds, no species which is exclusively confined to the Glenkiln group has yet been found in this series, nor any form characteristic of the Birkhill group. The assemblage collected comprises graptolites common to the Glenkiln and Hartfell groups and a few zonal Hartfell forms. There is always, however, a remarkable similarity in the palæontological types.

The band is further interesting from the fact that certain seams in it have yielded fragments of trilobites, at Corfardine on the Scar Water and in Clodderoch Burn, a tributary of the Dalwhat Water. These fragments are obscure or indefinite, and by themselves they have not been of much service in fixing the age of the beds containing them. In the Explanation of Sheet 9 (Appendix, p. 59) reference is made to the specimen obtained by Professor Harkness from a slate quarry at Corfardine—a cast in black shale of one-half of the pygidium. Mr. Etheridge, senior, was inclined to refer it to either of two genera, *Cybele* or *Enerinurus*, probably the latter; though its indefinite character scarcely justifies the giving of a name to the specimen. The fossil might be referred to the Llandeilo or Caradoc Rocks but hardly to any higher group. A trilobite found by Mr. Macconochie in the Clodderoch Burn exhibited imperfectly the thorax, pygidium, and a small portion of the carapace, and was referred to the genus *Phacops*. Though the evidence furnished by these imperfectly preserved trilobites is indefinite, the assemblage of graptolites suggests that the age of the beds is Caradoc.

Beginning with the north-eastern prolongation of the band in Sheet 9, we find admirable sections in the Scar Water immediately to the north of Corfardine Farmhouse, northwards to the mouth of the tributary Auchenhessnane Burn. Though the general dip is to the north-west at high angles, the beds are evidently repeated by sharp folds. They consist of flagstones and shales with thin hard ribs of a golden yellow colour, from a quarter to half an inch thick, alternating with blue shales, and they are occasionally associated with grey-

wackes. They occupy the bed of the stream southwards to a point nearly opposite Corfardine Farmhouse, where they are associated with dark blue shales having layers of black shales in thin seams or bands. These black seams have afforded the following assemblage of fossils characteristic of the *Pleurograptus linearis* zone:

Dicellograptus Morrisi (Hopk.)
,, *caduceus* (Lapw.)
Climacograptus like *tridentatus* (Lapw.)
,, *bicornis* (Hall.)
,, *bicornis* (Hall), with very long radicles.
Leptograptus flaccidus (Hall.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Retiolites (Neurograptus) fibratus (Lapw.)
Siphonotreta micula (M'Coy.)

The Corfardine slate quarry, from which Professor Harkness obtained his trilobite fragment, has been opened on the hill slope about 500 yards west of the farmhouse, in grey and blue shales, slightly cleaved, and enclosing worm tracks. A pygidium of *Phacops* and an *Orthoceras* were found in the debris during 1895.

South-westwards, beyond the watershed between the Scar and Shinnel Waters, the same series reappears in a tributary of the Shinnel that drains the south slope of the Bennan Hill. At a point about half a mile up this tributary the dark seams in the blue and grey shales yielded *Climacograptus bicornis* and *Diplograptus foliaceus*. Similar beds on the same line of strike yielded *Climacograptus bicornis* in a small burn south-west of Corfardine on the Laight Hill above the Scar Water.

Clodderoch Burn.—On the western side of the Shinnel Water a good section is to be seen in the Clodderoch Burn, which joins the Shinnel about 300 yards above the village of Tynron. Near the head of the burn, at a point about 400 yards above the hill-road or footpath leading to Moniaive, grey shales are well exposed with black seams or films from an eighth to a quarter of an inch thick. The mode of occurrence of these black seams or films recalls the lithological type of the Lower Hartfell Shales in Polmorlach Burn (Sheet 15). They have furnished the following graptolites, which are likewise characteristic of the *P. linearis* zone:

Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
,, *tridentatus* (Lapw.)
Retiolites (Neurograptus) fibratus (Lapw.)
,, ,, slab covered with small form.
Dicellograptus Forchhammeri (Gein.)
,, *elegans* (Carr.)
,, *Morrisi* (Hopk.)
,, like *anceps* (Nich.)
Leptograptus sp.

On the left bank of the stream, at the same place, green sandy mudstones or shales weather in long pencil-shaped fragments, and contain derivative mica. They somewhat resemble the type of Barren Mudstones in the Moffat region. They are contorted and thrown into sharp folds. Near the hill-path leading to

Moniaive, the gradual passage of these mudstones and shales into greywackes, grits and shales is visible on the left bank.

Lower in the burn, at a point about 100 yards below this footpath, on the right or south bank, clayey shales or mudstones are associated with blue and black seams containing graptolites. In the clayey shales the specimen of *Phacops* was found, together with fragments of *Orthoceras*, while the dark or black seams referred to in a preceding paragraph furnished *Leptograptus flaccidus*, *L. capillaris*, and *Diplograptus*.

Further down the stream a ravine affords a good section of strata that present similar lithological characters, and have yielded at one point *Diplograptus foliaceus*, *Leptograptus flaccidus*, *Climacograptus bicornis*, and *Corynoides*.

Dalwhat Water.—Southwards along the same strike, these beds are again exposed in the Dalwhat Water, near Caitloch. Near the cave on the banks of the stream massive greywackes and grits appear; at the north limit of the Caitloch Wood shales are seen. For some distance up stream these shales are met with, containing the hard yellow-weathering ribs from a quarter to an inch thick. The blue and grey sandy shales include occasional dark or black seams yielding graptolites. The hard ribs are sometimes from three to four inches thick at the upper limit of this section, and are occasionally associated with greywackes.

The intercalation of the dark or black seams in the grey or blue shales is well seen at a point about 500 yards up stream from Caitloch. The following forms were there obtained from the black seams:

Pleurograptus or *Amphigraptus*.
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Dicranograptus sp.
Dicellograptus pumilus (Lapw.)

These beds can be followed along the strike across the Craigdarroch Hill to the Ballinie Burn, where at a point about three-quarters of a mile west of Ballinie Farmhouse they have been found to contain *Diplograptus foliaceus*, *Climacograptus bicornis*, *Dicellograptus*, *Corynoides*, &c. Some of these forms were obtained also from an exposure in a burn on the hillside a short distance south of Ballinie.

To the south-west the same group of flagstones and shales reappears with a general dip to the north-west in the Pointfoot Burn which joins the Castlefern Burn about half a mile south of Minnygryle shepherd's house. Thence they can be followed at intervals towards the streamlet draining into Regland Loch. In the Whitecairn Burn, about a quarter of a mile below its outlet from that loch, a section of mudstones like the Barren Mudstones of Moffat includes a thin seam of dark or black shales which may possibly be found to contain *Dicellograptus anceps*.

In the burn at Regland shepherd's house, about three-quarters of a mile south of Margree, and again in the Margree Burn, re-

presentatives of this group, consisting of dark blue and grey shales with black seams, have yielded the following fossils:

Leptograptus flaccidus (Hall.)
Dicellograptus caduceus (Lapw.)
,, ,, or *Morrisi* (Hopk.)
Dicellograptus like *anceps* (Nich.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Retiolites sp.

The same strata can be followed in small exposures at intervals to Ardoch and Gordonston, a mile and a half north-east of Dalry. In the Ardoch Glen, 200 yards south from the farmhouse of Ardoch, cleaved dark-blue shales have afforded *Climacograptus bicornis*, *Diplograptus foliaceus*, *Dicellograptus Morrisi*, *Dicellograptus caduceus* (?), and *Leptograptus flaccidus*. Again, in the Gordonston Burn, that unites with the Ardoch stream to form the Torlane Burn, the following fossils were obtained from these beds:

Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Dicellograptus Morrisi (Hopk.)
Retiolites (Neurograptus) fibratus (Lapw.)

River Ken North of St. John's Town of Dalry. —The section in the river Ken northwards from Dalry displays very massive greywackes and grits. At the Miltonpark Burn, where a strip of alluvium flanks the river on the east bank, the banded series of Corfardine on the Scar Water reappears, composed of blue-grey shales with thin hard ribs, weathering yellowish brown. Further up stream it is well seen in knobs in the river, dipping N.N.W. at 40°; the cleavage angle being 60°. At this locality four thin hard ribs, weathering yellow, were observed to be interleaved in blue-grey shales within a thickness of six inches of strata. Still higher on the west bank, and in the bed of the stream when the water is low, these dark blue shales with black seams extend for a distance of about 200 yards, dipping persistently to the N.N.W. at high angles, and yielding specimens of *Dicellograptus*, *Climacograptus*, and *Diplograptus*. Fragments of graptolites are very abundant, but few determinable forms are obtainable. The beds are evidently repeated by sharp isoclinal folds.

Beyond some blanks in the section, massive greywackes and grits appear to the west of Milton. Dark blue shales, greywackes, and black grits, at a point on the east bank about 150 yards south of the mouth of Barskeoch Burn, yield specimens of *Dicellograptus* and *Climacograptus* These strata occupy the river section northwards to the mouth of the Barskeoch Burn, which joins the Ken from the west about a quarter of a mile north of Barskeoch Mains. This stream, at various points in its course, displays a section of black shales, so crushed and shattered, that few determinable graptolites can be got from them. About 250 yards west from the road leading to Dalry they have yielded *Diplograptus foliaceus* and *Climacograptus*

Schärenbergi; a few yards west from the same road *Climacograptus* was found.

The section in the Ken, where this burn joins it, does not very satisfactorily show the relations of the cherts and black shales, which there crop out to the coarse sediments. The cherts, as seen on the west bank at the north edge of the alluvial patch, are grey in colour and contain abundant radiolaria. But they are here succeeded by greywackes and grits, and it is evident that the black shales are faulted out. The east bank of the Ken, however, affords two exposures of the black shales associated with greywackes, &c., but too shattery to yield graptolites for determination. The occurrence of the cherts and black shales at this point in the Ken section indicates that the adjoining sediments must be younger than Upper Llandeilo time, and younger than part of the Lower Hartfell black shale series.

North from the mouth of the Barskeoch Burn, the Ken flows over a succession of grits, greywackes, and shales similar to those above described. Below the junction of the Pulharrow Burn, the river has cut a deep gorge through these strata; indeed, at this part of the section the grits are very massive, and in some features differ but slightly from the grits of Tarannon age. Here and there throughout the grits, lenticular seams, patches, and bands of grey and blue shales appear, which give them an irregular character. The regular system of jointing, which, in unaltered areas, is such a conspicuous feature of the Queensberry or Llandovery grits, is not here present. At one point in the gorge the grits become pebbly like the "Haggis Rock," and contain well-rounded pieces of quartz, with fragments of felspar, black shale, and igneous rocks, &c. At the south end of the alluvial land at the mouth of the Pulharrow Burn, flaggy shales appear with a north-west dip, which may be on the horizon of the flaggy shales of Barlae.

iv. Black Shale Bands between Whing Burn, Euchan Water, and Beninner Hill, near Cairnsmore of Carsphairn.

Whing Burn (Euchan Water, a mile and a half south-west of Sanquhar; Sheet 15 of Survey Map).—Along a line of axial folds which stretches from the Whing Burn, near Sanquhar, south-westwards by the Scar Water to the Lorg (river Ken) and Beninner Hill, near Cairnsmore of Carsphairn (Sheet 9), excellent sections expose the relations of the Arenig volcanic rocks to the radiolarian cherts and Glenkiln black shales. In some of the arches the type of diabase or andesite-lava, so common at Ballantrae and throughout the Southern Uplands, is well represented, and the radiolarian cherts, which immediately overlie it, together with the Glenkiln black shales.

In a small burn which joins the Whing Burn from the east, near the Ulzieside Plantation, the pillowy lava is faulted against greywackes on the north side, while on the south side, red mud-

stones and cherts appear, which are followed by an outcrop of black shales.

In the Tongue Burn, another tributary of the Whing Burn west of Cairn Hill, about 300 yards above its mouth, the following fossils were found in black shales associated there with grey shales:

Dicranograptus ramosus (Hall.)
Climacograptus bicornis (Hall.)
Dicellograptus Forchhammeri (Gein.)
,, sp.
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)
Retiolites sp.
Acrotreta Nicholsoni (Dav.)
Hyalostelia fasciculus (M'Coy.)

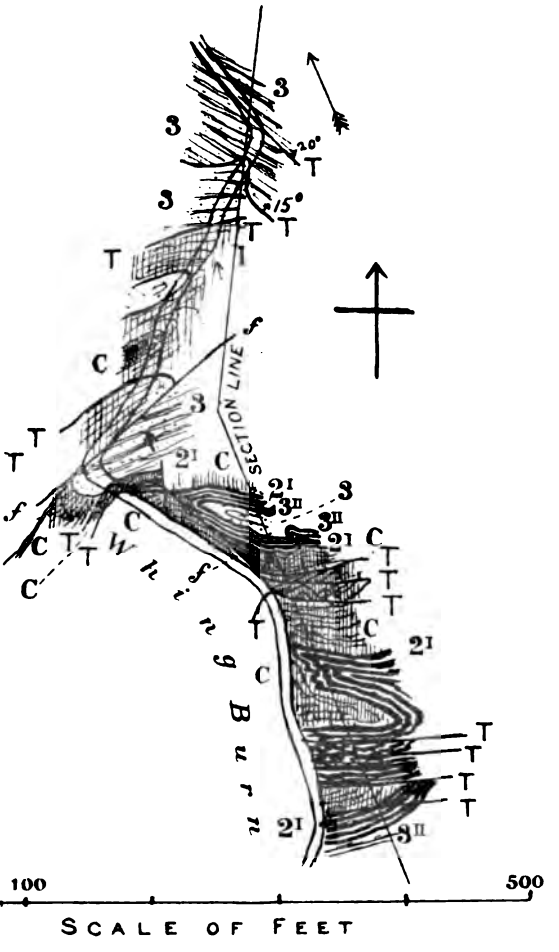


FIG. 83.—Plan of Strata in Whing Burn, near Shieling Knowe, S.W. of Sanquhar.

1. Red mudstone (Arenig). C. Radiolarian chert. 2I. Glenkiln Shales. 3II. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). f. Faults. T. Thrust-faults.

From this assemblage of organisms, as well as from the mode of occurrence of some of the forms, this band may be regarded as representing the basal portion of the Lower Hartfell black shales. The shells occur in profusion in a single layer, and likewise the arms of *Dicellograptus*.

In the Whing, northwards from the foot of the Tongue Burn, there are frequent exposures of black shales, and radiolarian cherts with greywackes and shales. The strata are traversed by numerous reversed faults which disturb the relations of the rocks (Figs. 83 and 84). About eighty yards below the junction with the Tongue Burn, folded and contorted black shales occur, with a few feet of chert in the heart of the black shales. The black shales yield the following fossils:

Didymograptus superstes (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)

Further down stream, at a bend about a quarter of a mile north from the foot of Tongue Burn and 70 yards north from southern limit of ground-plan (Fig. 83), the black shales have

FIG. 84.—Section in Whing Burn along the line shown in Fig. 83.

supplied a fine suite of Glenkiln graptolites. In this part of the section admirable examples of the repetition of the beds by reversed faults are to be found. Here, on the right bank of the stream, the cherts occur in the heart of the black shales. The latter have yielded the following Glenkiln fossils:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
Dicellograptus patulosus (Lapw.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
Diplograptus euglyphus (Lapw.)
Lasiograptus bimucronatus (Nich.)

A few yards further down, on the right bank of the stream, well-banded black shales occur with cherts, and are overlain by greywackes (3 in Fig. 83). This exposure affords well preserved graptolites belonging to the Glenkiln horizon, in particular, fine specimens of *Didymograptus superstes*. The following list was obtained from this locality:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *patulosus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)

Though in the Whing Burn the strata are much disturbed, and fossils are not easily obtained, the black shales associated with the cherts yield characteristic Glenkiln forms where the fossils can be determined. Above the point of junction with the Tongue Burn, black shales occur on several folds with rusty greywackes and shales. On the top of a waterfall formed of shales and greywackes, a band of black shales may be noticed, with alternations of grey and black seams, three to four feet broad. This band contains *Corynoides calycularis* in profusion, *Climacograptus bicornis*, *Cryptograptus tricornis*, and *Diplograptus foliaceus*.

Cramley Burn (Tributary of the Glenmaddie Burn immediately to the west of the Whing Burn).—About a quarter of a mile above the junction of this stream with Glenmaddie Burn, the Arenig lava is exposed on a green grassy knoll on the left bank of the stream, and on the south side of the lava the cherts are seen. A few yards further down stream the grey and dark cherts appear with black shales in separate folds. In the second outcrop of black shales in this burn, the following fossils have been obtained:

Didymograptus superstes (Lapw.)
Dicranograptus formosus (Hopk.)
Dicellograptus sextans (Hall.)
Dicellograptus patulosus (Lapw.)
Climacograptus Schärenbergi (Lapw.)
Dicranograptus ramosus (Hall.)

On the moor between the Cramley and Glenmaddie Burns, a small exposure of the lava may be noticed, and in the Glenmaddie Burn, at various places, the black shales and cherts are seen.

To the south-west of Glenmaddie Burn, on the moor between that stream and the Glen Burn, two prominent grassy knolls, which rise above the general level of the ground, consist of the typical diabase-lava, slightly decomposed and showing pillowy structure. The more easterly mass, named "The Earl's Seat," is about 70 yards long. A few yards to the east of it the radiolarian cherts are visible, as the only exposure of sediments round this igneous projection. The western mass, over 200 yards in length, slopes gently off into the surrounding ground. At one place on the north-west side of this arch, the radiolarian cherts dip at a gentle angle to the north-west, and a few yards further north the black shales are visible. On the south side of the fold the red mudstones are seen, with the black shales close at hand to the south.

Along the line of strike of these arches, no section of the solid rocks has been cut by the Glen Burn, the watercourse lying in boulder clay; but on the hill to the south-west of that stream, the volcanic rocks, cherts, and black shales reappear. On the hill slope facing the Glen Burn, and about 200 yards from the stream, the radiolarian cherts and black shales are repeated several times over a distance of 300 yards across the strike. Above the level of the 1250-feet contour line, and within 200 yards of the cairn on the hill-top, measured in a north-west

direction, the diabase-lava is exposed. The cherts are seen at the north-west corner of the mass, and highly puckered black shales and cherts occur in the neighbourhood of the cairn.

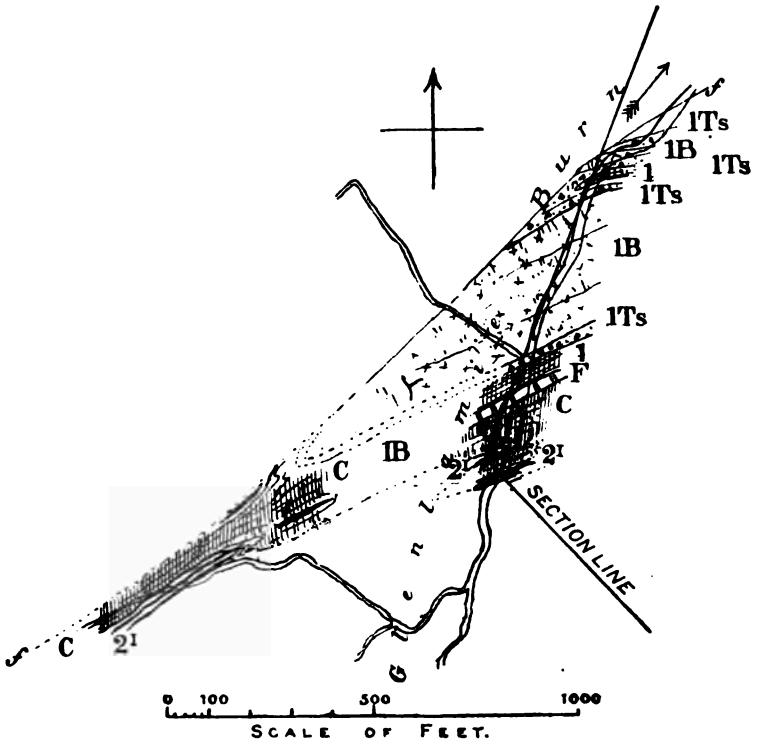


FIG. 85.—Plan of the Strata near the Head of Glenlarie Burn, 4½ miles S.W. from Sanquhar.

1B. Diabase-lavas. 1Ts. Tuff. 1. Red mudstones. C. Radiolarian chert. 2I. Glenkiln Shales. 3II. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). F. Felsite dyke.

The Glenlarie Burn, another tributary of the Euchan Water, a little further to the west, supplies sections at its sources where the relations of the volcanic rocks to the overlying sediments are displayed. Immediately to the west of the Mid Rig, this burn divides into two branches, both of which give sections of the Arenig Rocks. The west branch, about 300 yards above the fork, displays pillowy lava and tuff, resembling the Ballantrae volcanic series. The accompanying diagrams (Figs. 85, 86) show the arrangement of the strata there. Grey and dark radiolarian cherts are pierced by a felstone dyke, which shows fluxion structure along its edges. Red mudstones succeed on the north, followed by a bed of tuff resting on a mass of diabase-lava, showing pillow-structure, about eighty-five yards in breadth (1 B, Figs. 85, 86). To the north this lava is followed by three

feet of red mudstones, six to eight feet of lava, and three feet of tuff. Beyond this point no rocks are exposed till near the fork. The main mass of the volcanic rocks in this fold, as elsewhere, is shown to underlie the radiolarian cherts; and at one point tuff is associated with the cherts.

This section is probably bounded by a fault along the north-west side, for near its northern limit greywackes appear at the base of the steep grassy slope on the north side of the stream (3, Fig. 86). Eastwards, where the burn flows through alluvium and peat, the lava appears on a grassy knoll, on which a sheep-stell is built, above the fork. This rock can be followed eastwards across the east branch of the Glenlarie Burn to the moor beyond. Two small exposures of lava lie to the south of this main fold, one in the east branch of the burn and another on the moor to the east. Two felstone dykes are seen in the east branch a few yards to the south of the second exposure of lava. Black shales and black flints appear further up the some rivulet.

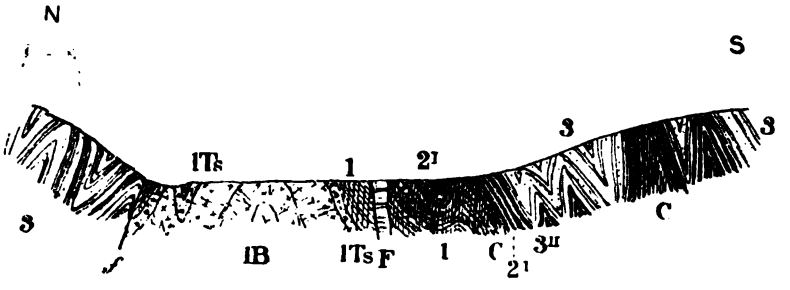


FIG. 86.—Section near the head of Glenlarie Burn along the line marked in Fig. 85.

Along the strike of the main fold of Arenig lava in Glenlarie Burn, the radiolarian cherts can be followed westwards for nearly a mile to the crest of the watershed between the Euchan and Scar Waters. At a few places, the black shales can be found both on the north and south sides of this fold.

On the watershed between the Glenlarie Burn and a tributary of the Scar Water east of Polgown, another fold of the radiolarian cherts with the black shales is traceable at intervals for a distance of 600 yards.

Upper Basin of the Scar Water.—Crossing the watershed between the Scar and Euchan Waters, we will now follow the development of the Arenig rocks and overlying sediments in the upper part of the basin of the Scar Water.

At the head waters of the Polgown Burn interesting sections appear of the Arenig Rocks; one in particular is deserving of special mention, because intrusive dolerite is associated with the normal pillowy lava. It occurs about half a mile to the north-west of Polgown shepherd's house, in a streamlet draining a hill called the Rough Naze. In this rivulet, blue shales crop out

(3, Fig. 87, south limit of diagram) about 300 yards above its point of junction with the Polgown Burn. These are faulted against massive reddened cherts which occupy about ten paces of the section, and are followed by highly puckered black shales (2^{l}) pierced by a felsite dyke (F). To the north of these shales radiolarian cherts (C) appear, followed in descending order by a mass of pillowy lava (1 B), about twelve paces broad, which

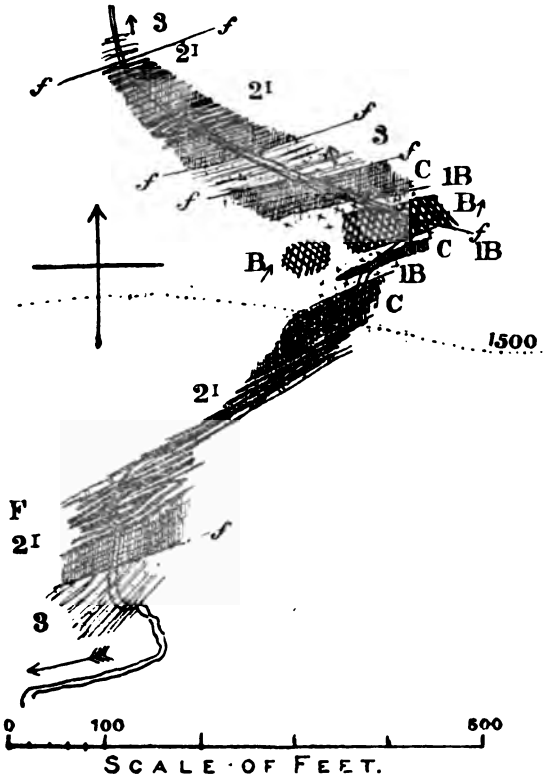


FIG. 87.—Plan of Strata in Streamlet near Polgown, Scar Water.

1B. Arenig lavas. 1B*T*. Intrusive dolerite (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywake and shale (Caradoc). F. Felsite dyke. f. Fault.

occupies the stream course at the prominent bend, and for some distance below it, and contains an inlier of red mudstones (C). Just above the bend, the pillowy lava is succeeded by coarse dolerite (B*T*), which is there faulted against the radiolarian cherts. On the grassy slope in the angle formed by the bend of the burn there is a boss of dolerite, probably the continuation of the mass in the burn a few yards to the north-east.

The radiolarian cherts (C) can be followed for a distance of ten paces north of the dolerite, when they are succeeded by greywackes and shales (3) for a space of 29 paces. The cherts

reappear to the north with an infold of black shales (2[1]), from which the following fossils were obtained: *Didymograptus superstes*, *Dicellograptus sextans*, *D. Forchhammeri*, *Climacograptus bicornis*, and *Cryptograptus tricornis*.

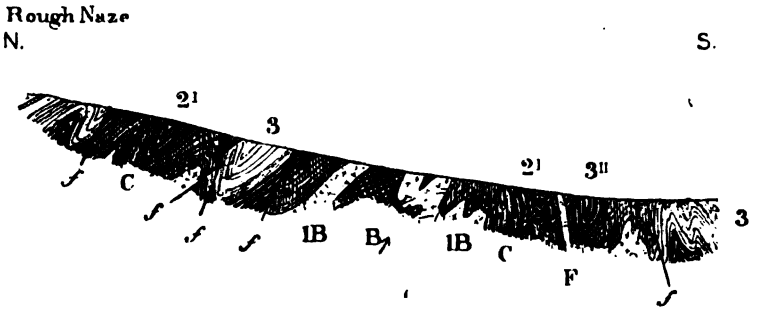


FIG. 88.—Section along the streamlet shown in Fig. 87.

About 200 yards to the east, two exposures of volcanic rocks may be seen on the grassy slope, evidently on separate folds, not far from each other, and parallel. The northern one shows diabase-lava, with an infold of chert and bounded by chert. The southern exposure contains both intrusive dolerite and the diabase-lava, with Arenig cherts and black shales, and is prolonged to the north-east. By means of chert debris it can be followed for a distance of half a mile in that direction.

Along the same strike the radiolarian cherts and black shales are exposed in another tributary of the Polgown Burn, associated with intrusive dykes. They reappear on the south-east slope of the Rough Shoulder, in the Dalgonner Burn, on the moor south of Corse Hill, and in the Polskeoch Burn at the very head of the Scar Water.

Water of Ken (Tributaries in Sheet 15 of the Survey Map).—Proceeding westwards along the general line of strike of the axial folds described in the foregoing pages, to the Polvaddoch Burn—a tributary of the Ken to the west of Polskeoch—we find a considerable development of black shales repeated by sharp folds, the radiolarian cherts being also exposed. About 200 yards south from the junction of the Pot Burn with the Polvaddoch Burn the black shales have yielded *Didymograptus superstes*, *Cœnograptus pertenuis*, and *Dicellograptus moffatensis*. At an exposure of black shales to the north-east of this locality, and about the 1600-feet level, the following forms were collected: *Cœnograptus gracilis*, *Dicranograptus zic-zac*, *Diplograptus tricornis*, and *Dicellograptus sextans*.

Westwards beyond the Lorg Hill, which separates the Polvaddoch and Lorg Burns, a section of great interest is displayed on the Rough Craig, overlooking the Lorg shepherd's house on the north-east side of the valley (see ground plan, Fig. 89). The hill-top is covered with peat and turf, and the Rough Craig

appears as the observer begins to descend the steep slope towards the Lorg Burn, about the 1600-feet level. This section shows the sequence from the Arenig lavas and overlying cherts to the Glenkiln band of black shales. No coarse sediments are here

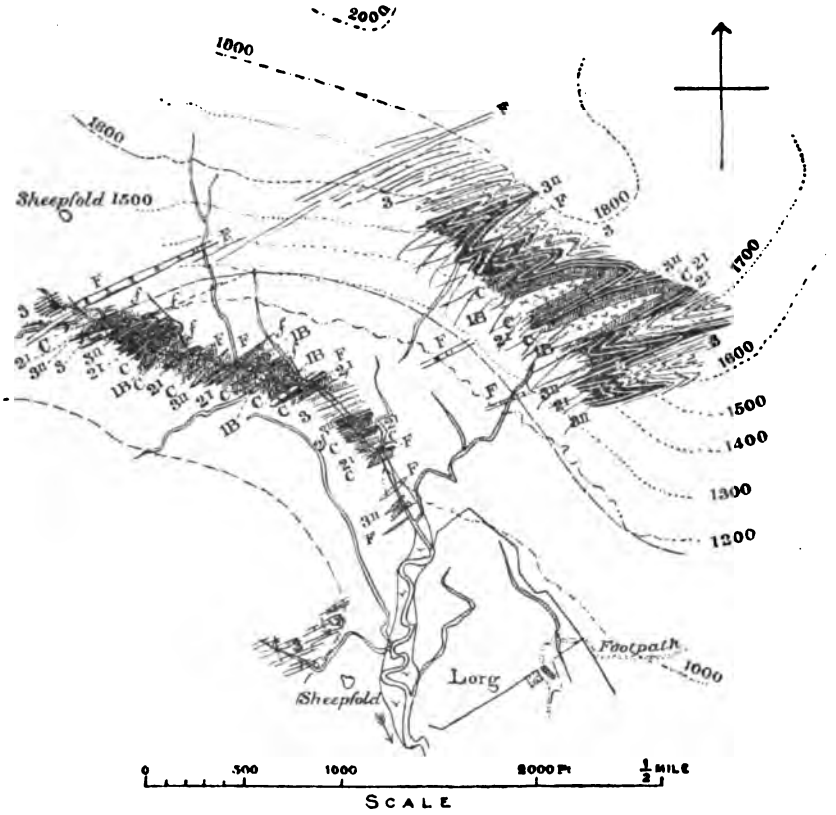


FIG. 89.—Ground Plan of Strata in Lorg Burn and Rough Craig, Water of Ken, Kirkcudbrightshire.

1B. Arenig lavas. C. Radiolarian chert. 2l. Glenkiln shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). F. Felsite dyke. f. Fault. Dotted lines, contour lines. Interrupted lines, upper limit of glacial deposits.

associated with the volcanic rocks, cherts, or black shales, till we reach the greywackes and shales overlying the Glenkiln-Hartfell band of black shales.

At the northern limit of the section, where the black shales occur as rapid folds in the midst of greywackes and shales, the following fossils were obtained: *Cœnograptus gracilis*, *Lasiograptus bimucronatus*, *Cryptograptus tricornis*, *Climacograptus*, and *Corynoides calycularis*. Passing south-eastwards along the face of the crag, where a felsite dyke traverses the black shales and

greywackes, the observer finds about the 1600-feet level highly puckered black shales, terminating in sharp V-shaped folds in the upper portion of the crag, and there plunging underneath the overlying greywackes and shales. Still further south, the

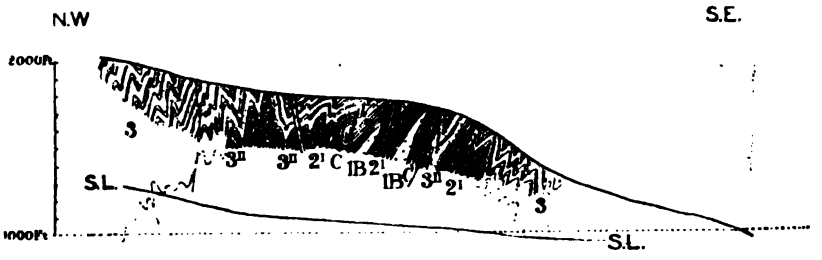


FIG. 90.—Section along the Rough Craig, as in Fig. 89.
S.L. Stream level.

grey cherts appear in a sharp fold of the black shales nosing out northwards, and along the strike of this same fold the black shales are seen, followed by the overlying greywackes and shales higher up the crag. Crossing this sharp fold, we can trace cherts round the syncline of black shales, and they are succeeded by a fine exposure of the fine-grained diabase-lava occupying the core of an arch, the breadth of the exposure of lava being about 30 yards. Here the rocky craig terminates, and the rock-exposures peer through a covering of grass. Still there is evidence of the occurrence of the lava on a second fold parallel with the foregoing, surrounded by the radiolarian cherts and black shales.

This section enables the observer to study the sharp folding and rapid reduplication of the strata. On the face of the crag, he may see along one and the same fold radiolarian chert, followed by black shales and greywackes and shales in the higher part of the crag. Hence, while along the face of the crag the rocks consist mainly of lava, cherts, or black shales, on the hill-top they are composed mainly or wholly of greywackes and shales.

Lorg Burn.—From the alluvial flats near the shepherd's house up to the fork, about half a mile above, this stream reveals a constant repetition of greywackes, black shales, and cherts, which, as a rule, are much shattered and cleaved (Fig. 91). Fossils are difficult to find in the black shales. The cherts sometimes show fine flaser-structure, and the beds are traversed by various dykes. Two or three very small exposures of the lava appear among the folds of chert, so much crushed and deformed as to be almost unrecognisable.

On the west side of the valley, facing the Lorg shepherd's house, a gloomy crag nearly a quarter of a mile in length, displays a fine section of Arenig cherts, black shales, and other sediments pierced by a great network of dykes. Here again

the black shales are so cleaved and indurated, that it is difficult to prove the horizon of the bands by means of graptolites. It is instructive, however, to note the manner in which the radiolarian cherts appear in small lenticles, plunging rapidly under the black shales. The greywackes and shales frequently come next to the cherts on one limb of the fold without the intervention of the black shales—a structure probably due to normal or reversed faults. This feature is specially noticeable on that part of the crag to the south of the main burn, on the declivity immediately to the south of the network of dykes.

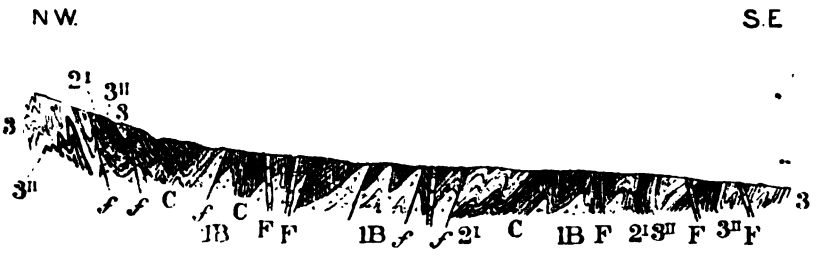


FIG. 91.—Section in Lorg Burn, above Lorg Shepherd's House, Water of Ken, Kirkcudbrightshire.

(Explanation as in Fig. 89.)

At the head of the main burn (south of Rough Cleuch) black shales have yielded the following fossils, which indicate that the zone may represent perhaps the passage beds between the Glenkiln and Hartfell groups:

Dicranograptus ramosus (Hall.)	*Climacograptus bicornis* (Hall.)
,, *Nicholsoni* (Hopk.)	*Dicellograptus sextans* (Hall.)
Cryptograptus tricornis (Carr.)	*Diplograptus foliaceus* (Murch.)

To the north of the dykes, a constant repetition of radiolarian cherts and black shales extends as far as the Rough Cleuch, at the head of which a deep ravine has been carved out of the black shales and cherts. North of the Rough Cleuch, the presence of the cherts is indicated by debris of that material, seen at intervals. The black shales also appear on the slope facing the Alwhat Burn, one of the tributaries of the Lorg Burn.

The top of the Ewe Hill is more or less covered with thin peat and turf, and hence it is not possible to trace continuously the folds of chert and black shales so well displayed on the crags in the Lorg valley. The western slope of that hill, overlooking the Spout Burn, has a grassy covering, but occasional exposures of the radiolarian cherts and black shales may be noticed above the limit of the glacial deposits. For a distance of nearly a third of a mile along the slope, the cherts and black shales are brought to the surface again and again. Many, if not most, of the folds appear to be nosing out as we descend the slope, and hence the overlying sediments are exposed in the same line of

strike in the bed of the stream in the centre of the valley. On the other hand, towards the top of Ewe Hill, the cherts appear, and seem to cover a considerable breadth of ground. It is highly probable, therefore, that the arches of Arenig cherts and black shales may extend across the Ewe Hill to the crag on the west side of the Lorg valley.

In the Spout Burn, about half a mile above its junction with the Holm Burn, and again about half a mile above that junction, the cherts and black shales are visible. About two miles to the south-west, the Arenig cherts and overlying black shales reappear on Beninner and Moorbrock Hills.

Beninner Gairy, Cairnsmore of Carsphairn.—The ridge of Beninner (2328 feet), forming the south-east spur of Cairnsmore of Carsphairn, has a rocky escarpment along its eastern face, composed of Silurian rocks, which have undergone more or less alteration in contact with the granite mass; portions of this gairy are precipitous, but the exposures of the Moffat series are readily accessible.

About 300 yards to the south of the cairn on the top of Beninner, four folds of the radiolarian cherts, associated with black shales, can be followed down part of the rocky escarpment. A few yards further north in the gairy, another small fold of the cherts is bounded by the black shales, and followed immediately by brown-weathering greywackes and shales, with abundant minute biotite of secondary origin. The cherts are slightly granulitised, and the black shales are changed into graphitic schist, with traces of graptolites.

Advancing northwards along the crag, the observer crosses fine-grained greywackes and shales with mica of contact origin, till at the bend due east of the cairn on the top of the mountain he comes upon an arch which brings in the Arenig volcanic rocks. On referring to the one-inch map (Sheet 9), it will be seen that the granite boundary, which crosses the Poldores Burn in an east and west direction, skirts the base of the Beninner Gairy, and thence curves towards the north-west along the base of the escarpment formed by the altered Silurian rocks. At the bend due east of the cairn on Beninner top, a fine development of the grey cherts in contact with the granite can be followed up the cliff for some distance. The alteration displayed by the cherts at this locality is not nearly so pronounced as at the granite margin south of Loch Doon, but they are granulitised.

The heart of this fold of cherts encloses a small exposure of volcanic rocks, partly bedded and partly intrusive, which measures about five yards broad by about fifteen yards long. The lava is vesicular, with garnets developed in the vesicles by contact alteration. It is granulitised, and contains abundant brown mica of secondary origin. In the centre of the altered lava there is a small mass of coarse-grained altered dolerite or gabbro. The cherts are succeeded by altered black shales on the south side of the fold, and these in turn towards the south-west by altered greywackes and shales.

Moorbrock Gairy.—The development of Arenig cherts on Moorbrock Gairy, one mile N.N.W. of Moorbrock shepherd's house, and on the crest of the ridge to the west, reaches a much grander scale than on Beninner Gairy. They are not much altered; indeed, radiolaria can be detected in many of the exposures though the rocks are slightly granulitised. Both the dark and grey varieties occur. The volcanic rocks have not been here detected in the cores of any of the folds of Arenig cherts.

A broad development of cherts on the gairy due east of the cairn on Moorbrock Hill, contains in its centre a trough of black shales, yielding characteristic Glenkiln forms. This synclinal fold occurs at the base of the crag and above the 1600-feet contour line. Inclusive of this fold of black shales in the centre of the mass, the distance from the southern boundary of this outcrop of chert to its northern limit is about 150 yards. The cherts are highly corrugated. Along the southern margin of the cherts, the black shales are visible not far to the north of an oval mass of intrusive granite in the gairy. The intrusive rock, being of less durable material, has been decomposed, and is surrounded by indurated Silurian rocks. On the crag above the small granite mass, the cherts may be seen to form tongue-shaped projections in the overlying black shales and dark gritty greywackes, due to the rapid folding of the strata. The black shales are sometimes thrown out by faulting, and the greywackes come in contact with the cherts. But at the top of the crag the black shales occur next to the chert on the south side of the fold. These black shales yield graptolites. The best locality for fossils, however, is the trough of black shales in the heart of the cherts at the base of the crag, east of the cairn, where the following species were obtained:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus zic-zac (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Dicellograptus patulosus (Lapw.)
Leptograptus flaccidus (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)

The black shales are not seen on the gairy along the north margin of this fold of chert; they are evidently faulted out. A dyke of acid intrusive rock runs up the cliff about the line of junction between the cherts and greywackes. The strata found in the gairy to the north of this point consist of greywackes, which show a considerable development of brown mica of secondary origin.

To the south of the small granite boss above referred to as occurring in the gairy, there are minor folds of the cherts and black shales. In the coomb-shaped hollow that forms the south half of the Moorbrock Gairy, drained by the White Burn, west of Glenhead, another exposure of cherts, grey and dark, of the nodular varieties, is nearly 150 yards broad. Along its north and south margins, the black shales appear, and they likewise

form a synclinal fold in the centre of the mass. This broad fold of the cherts can be traced westwards from the gairy of Moorbrock across the hill-top to the edge of the granite mass. The alteration of the chert is irregular; in places the rock is granulitised, while at other localities it merges into the fine granular quartz variety which is a phase of the extreme metamorphism that occurs near Loch Doon.

Band of Volcanic Rocks between the Kello and Euchan Waters, probably of Caradoc Age.

About two miles to the north of the belt of Arenig Rocks and Glenkiln-Hartfell black shales which stretches from the headwaters of the Ken to the Sanquhar basin of Carboniferous Rocks, a narrow zone of volcanic rocks runs more or less parallel, and traceable at intervals for three miles, from near the edge of the Sanquhar coal-field to the Poltallan Burn, one of the higher tributaries of the Euchan Water. Nowhere along their line of outcrop are these volcanic rocks associated with Arenig cherts or with black shales yielding characteristic Glenkiln graptolites. The fossils which do occur are common to both horizons. In the sequel we shall point out that several miles to the north of this line of outcrop, the radiolarian cherts and Arenig volcanic rocks are to be found in the area bordering the New Cumnock coal-field, where the characteristic Glenkiln graptolites are still met with in black shales. It is probable, therefore, that the narrow zone between the Kello and Euchan Waters may occupy a higher horizon than that of the Arenig volcanic series. Indeed, in the Poltallan Burn, tuff is interbedded in shales which contain graptolites that indicate a Lower Hartfell horizon.

Barr Moor (three miles S.W. from Sanquhar).—At the eastern limit of the volcanic zone a small exposure of black shales is met with in the Birk Burn, in the wood at the very edge of the Carboniferous basin. Black shales, containing nodules of greywacke and grit, or nodular masses of these materials, have there been laid bare by the denudation of the overlying thin cake of Carboniferous sandstone. In the west fork of this stream, about a quarter of a mile from the edge of the basin, a section on the right bank exposes upwards of 20 feet of lava, the vesicular character of which is well seen in weathered specimens. On the north side of the lava, in the bed of the stream, crushed dark blue shales occur, while on the south side blue shales are seen on the right bank.

The next exposure of the volcanic zone is to be seen in a small tributary of the Kello Water, about half a mile to the west of the outcrop just described, and nearly a mile from the foot of the stream. The burn flows over tuff, which has a grey matrix of volcanic debris, and contains bombs of diabase-lava. On the south side of this tuff, and in contact with it, black shales yield the following fossils:

Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Leptograptus flaccidus (Hall.)
Climacograptus sp.
Dicellograptus sextans (Hall.)
,, *Forchhammeri* (Gein.)

Westwards, the tuff is traceable by means of debris in drains to the March Burn, while occasional debris of vesicular lava also appears, as on the hill slope not far to the west of the March Burn. Still further west, in the Polsalloch Burn, a tributary of the Kello Water between the March Burn and Glengap, and two-thirds of a mile from its junction with the Kello, tuff appears in the bed of the stream. On the north side, grey greywackes and shales dip to the south-east. Though the actual contact of the tuff with the greywackes is not seen in the stream, they occur close to each other. The greywackes form the slope on the north bank, where they dip to the S.S.E. The tuff has here also a grey matrix, and contains blocks of vesicular lava.

South-westwards on the slope, about 100 yards distant from the Polsalloch Burn, the slaggy lava is exposed in a small scar, and reappears on the hill slope facing the Glengap Burn. A microscopic examination of a specimen of the lava from the latter locality shows that "only the felspars are preserved, which occur in the form of short laths, and are associated with carbonates and turbid decomposition products. The spherical amygdules are formed of calcite." On this slope, both slaggy lava and tuff are visible in a well-marked grassy feature through which they protrude. Black shales occur at one point on the south side of the volcanic rocks, followed immediately by coarse grits. Indeed, on the slope near the col between the Glengap and Poltallan Burns the grits become conglomeratic.

Poltallan Burn (Euchan Water).—In this burn, about 300 yards up from its junction with the Euchan Water, a band of tuff passes into an ashy grit, about eight feet broad. On the north side it is followed by dark blue sandy shales yielding *Diplograptus foliaceus*, *Corynoides calycularis*, and *Climacograptus*. The shales are much cleaved, but in certain seams *Corynoides calycularis* and *Climacograptus* occur in profusion. The tuff is also visible in the bed of the Euchan at the Euchanhead shepherd's house.

CHAPTER XVII.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC FORMATIONS IN THE DISTRICT BETWEEN NITHSDALE AND LOCH DOON—*continued.*

NEW CUMNOCK TO CARSPHAIRN.

Volcanic Area two miles E.S.E. of New Cumnock.

In the tract lying to the north of the Knipe Hill, and extending from the north-west margin of the Sanquhar coal-field to the area of Carboniferous rocks south of New Cumnock, there is an important development of the Arenig volcanic group and associated radiolarian cherts. Here, as elsewhere, the rocks are brought to the surface by means of isoclinal folds, and in one instance, south-west of Polshill, two miles east from New Cumnock, the contemporaneous and intrusive volcanic rocks are admirably seen. Indeed, of the various exposures of these rocks outside of the Ballantrae region, the Polshill tract ranks next in importance to that of Bail Hill, near Sanquhar.

The Burntonhill Burn, a small streamlet about three-quarters of a mile south-west of Polshill, exposes an isolated outcrop of the volcanic rocks and radiolarian cherts. The upper reaches of the stream show greywackes and shales, together with conglomerate bands having a shaly matrix, and merging into shaly greywacke with scattered pebbles. At a point about seventy yards above the farmhouse of Burntonhill, the red cherts are visible, greywackes and shaly conglomerate passing underneath them with an inverted dip. A few yards lower down the stream a small exposure of fine-grained vesicular lava is to be seen on the right and left banks, overlain and underlain by cherts. Further down, opposite Burntonhill Farmhouse, the greywackes, grits, and shales appear. An isolated outcrop of the red cherts occurs in the field to the east of Burntonhill Farmhouse. In the Elder Burn, about 200 yards to the east of Burntonhill, the basic lava rises at one point, and it also occurs in the adjoining field. Still further east, in a field adjoining the Gatelochside Burn, the lava is visible at many points within a small radius, forming smooth glaciated surfaces peering through a thin superficial cover.

Gatelochside Burn.—One of the best sections of the volcanic rocks in this area is met with in the course of this

stream which joins the Nith, 400 yards east of Blackwood Farmhouse, just before it enters the Carboniferous area at Gatelochside. For a distance of 300 yards to the south of the fault bounding the Carboniferous area, the burn flows through a narrow gorge or wooded glen, showing excellent exposures of the igneous rocks. The lava is visible immediately to the south of the fault, and about 100 yards up from the fault, the red radiolarian cherts are seen in the gorge. Further up stream, at a point near a waterfall about 200 yards above the fault, the red chert and jasper are seen on both banks of the stream, underlain and overlain by the lava. Here, above a bend in the stream, the cherts are again visible on the right bank, forming an infold of the volcanic rocks.

The southmost exposure of the volcanic rocks in this stream, about 300 yards to the south of the Carboniferous fault, displays the pillow-structure which is such a characteristic feature of the lavas in the Ballantrae region. The pillowy masses vary in size from a few inches to several feet across, and they display the concentric arrangement of the vesicles so common in the Ballantrae region. The lava is uniform in character, rather fine-grained and vesicular. A specimen of this vesicular lava (No. 6807) shows under the microscope "acicular microlites of felspar, chlorite, and magnetite. The original rock probably contained granular augite, but no trace of this mineral now remains. The microlites of felspar show a tendency to arrange themselves tangentially with respect to the amygdules. They give approximately straight extinction, and are therefore presumably orthoclase. It is possible that a second felspar occurring in irregular individuals may also be present." The red cherts and jasper are seen resting on the lavas on the top of the bank at this locality.

In this volcanic area, as already noted elsewhere, intrusive igneous rocks are associated with the bedded lavas. A small intrusive patch of dolerite is seen to the west of Gatelochside Burn, measuring about 200 yards in length and about 60 yards in extreme width. The main mass of intrusive rocks, however, lies to the east of Gatelochside Burn, and runs nearly east and west for a distance of about half a mile, terminating westwards in the Garpool Burn close to the granite mass that stretches as a narrow belt from Meikle Westland to the Knipe Hill. This mass consists of a green coarse-grained ophitic dolerite, well seen in various old quarries to the south of Polshill. It is probably intrusive in the lavas, for though the exposures are few, the contemporaneous slaggy rocks are to be seen at various points in the fields on the north side of the intrusive mass and at one or two points on the south side.

The cherts are seen at one point about 150 yards to the south of the road leading to Polshill Farmhouse. They are there close to the intrusive mass, while the slaggy lava is visible on a knoll close at hand. Along the northern margin of the bedded lavas neither the cherts nor the black shales are observable. Indeed,

the evidence is obscured by drift, and the rock actually seen at the roadside near Polshill consists of greywacke. In like manner, round the southern margin of the mass, the cherts and black shales are concealed from view.

One interesting feature connected with this area of volcanic rocks south of Polshill is the contact alteration induced on the slaggy lavas by the granite intrusion, which is well seen at a point in the Garpool Burn about 500 yards south of the road leading to New Cumnock, and also in the small tributary stream (see page 647).

Nether Cairn (one mile east of Polshill).—Eastwards from Polshill towards Marchburn Farmhouse, several arches of the radiolarian cherts occur. At the farmhouse of Nether Cairn the volcanic rocks appear, composed of typical slaggy lava (diabase). The cherts are visible in a streamlet on the south side of the lava, followed by the "Haggis Rock" or fine conglomerate. They are also seen in the middle of the area occupied by the lava to the west of the farmhouse, here forming probably a synclinal fold.

March Burn.—In this burn which drains the northern slope of High Cairn Hill and joins the Nith near the county boundary, the red mudstones crop out a few yards above the bridge, followed by red grit becoming conglomeratic. A short distance up stream, where the rocks are sheared to some extent, blocks of stained diabase occur in red mudstones. Where the stream takes a bend at a right angle, red greywackes and shales are seen on the left bank and red jasper in the channel of the stream. On the right bank red mudstone bands contain lenticles of a purple slaggy diabase, with small vesicles, well seen at the base of the cliff. The small tributary that joins the March Burn about 200 yards above the high road to Dumfries, exposes purple diabase associated with the red chert and followed by grits.

Dempster's Glenmuckloch.—Again, at the edge of the Sanquhar coal-field, about a mile east from March Burn, Arenig lava appears in a burn that joins the Nith at Partland Place. The red cherts with radiolaria are met with on the south side of this outcrop. In the burn at Dempster's Glenmuckloch, on the north side of the Nith near the farmhouse, the cherts occur, associated with greywackes and grits, the latter being visible at the waterfall. Along the margin of the Silurian area, from Hillhead west to the Nith, occasional exposures of pebbly grit mark the position of the Haggis Rock.

Glenkiln-Hartfell Shales in Polmorlach and Polhote Burns.

Polmorlach Burn.—Having described the important volcanic area of Polshill, near New Cumnock, we may now consider the evidence for connecting the Arenig volcanic rocks and cherts of that district with the graptolite-bearing bands

belonging to the Glenkiln and Lower Hartfell horizons. The Polmorlach Burn furnishes important information from certain fossiliferous bands which yield an assemblage of fossils characteristic of the Glenkiln group and of the lower zones of the Hartfell black shales. This burn is about half a mile distant from the county boundary between Ayr and Dumfries, and about two miles from the edge of the Carboniferous rocks east of New Cumnock. It rises on the slope of the High Cairn Hill, and after traversing the Silurian area for about a mile, enters the north-west corner of the Sanquhar coal-field. Above the limit of the Carboniferous rocks, greywackes and shales are seen, the former being rather massive. No fossils were obtained from any of the shale bands associated with these greywackes.

About a mile up from the road between New Cumnock and Sanquhar, a band of igneous rock occurs as a lenticle in dark blue shales in the bed of the stream. It is about five feet broad, can be followed along the strike for about ten feet, and may be from fifteen feet to twenty feet in length. Under the microscope this rock (No. 6809) shows "numerous large chloritic or serpentinous pseudomorphs after augite. The matrix is too highly altered for determination, but it is apparently non-fragmental. The rock contains irregular patches of calcite, and is traversed by veins filled with calcite. Pyrite is abundant." This lenticular mass probably represents the Lower Caradoc volcanic zone. A few yards above this point, flaggy shales dip to the S.S.E.; they consist of alternations of dark blue and grey sandy shales. The following fossils were obtained from the dark seams at this point:

Dicranograptus sp.
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Dicellograptus sp.
Glossograptus Hincksi (Hopk.)
Climacograptus caudatus (Lapw.)
,, *Schärenbergi* (Lapw.)
Corynoides calycularis (Nich.)
Acrotreta Nicholsoni (Dav.)

A few yards further up, in dark blue-black seams alternating with grey seams, the following forms were obtained:

Amphigraptus radiatus (Lapw.)
Leptograptus flaccidus (Hall.)
Corynoides calycularis (Nich.)
Dicellograptus sp.
,, *moffatensis* (Carr.)
Glossograptus Hincksi (Hopk.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Acrotreta Nicholsoni (Dav.)

At the places just mentioned, the sandy layers yield abundant worm tracks.

Still a third locality, which has furnished a similar assemblage of graptolites, occurs a few yards higher on the left bank, at a sharp bend of the stream about 70 yards above the last-mentioned exposure of igneous rock. Here the shales consist of alternations of blue and grey bands with dark seams. The annexed list of graptolites was here obtained:

Dicranograptus ramosus (Hall.)
Diplograptus sp. (probably a dwarfed) *foliaceus* (Murch.)
Corynoides calycularis (Nich.)
Dicellograptus moffatensis (Carr.)
,, *elegans* (Carr.)

The shales at these various places have the same characters; they are well-bedded, flaggy, and break in platy masses. From their graptolites, it is clear that they represent the lower bands of the Lower Hartfell black shales. Although the lithological character of these shales has completely changed from their normal type in the Moffat area, the assemblage of fossils is persistent. The sediment is more arenaceous, and the only representatives of the Hartfell black shales are the thin dark seams intercalated in the sandy layers.

About ten yards above the last-named locality, an outcrop of black shales is charged with a characteristic Glenkiln fauna. This short space is occupied by grey and blue shales with dark seams of the Lower Hartfell type peculiar to this section, so that we have here a perfect passage downwards to the Upper Llandeilo Rocks. This band of black shales also differs considerably from the normal type of Glenkiln Shales in the Moffat area and in the southern part of the Sanquhar district. It is a pure black shale, splitting with an even fracture and free from the black siliceous ribs. Its strata dip to the S.S.E., and are much cleaved in places. They have yielded the following characteristic list of fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
,, *pertenuis* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Glossograptus Hincksi (Hopk.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *patulosus* var. *B.* (Lapw.)
,, *patulosus* (Lapw.)
Climacograptus bicornis (Hall.)
,, *cælatus* var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Leptograptus flaccidus (Hall.)
Acrothele granulata (Linnr.)

This assemblage of fossils, including twenty species, proves beyond all doubt that this band represents the Glenkiln black shales of the Moffat series. The most of the characteristic Glenkiln forms are here represented.

Unfortunately the radiolarian cherts are not exposed at this place, for as we ascend the burn these beds are faulted against greywackes and shales, the latter containing a band of felspathic grit, like the ashy grit in Kiln Burn, east of Bail Hill (p. 312). Crossing over the moor for a distance of three-quarters of a mile from Polmorlach Burn to the west branch of the March Burn, we meet with the green cherts with radiolaria (Arenig) at the head of the burn. A few yards down stream, beyond a blank in the section, a small exposure of black shales is to be seen in the bed of the stream. It is difficult to get material from these beds for examination. They yielded, however,

Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *Forchhammeri* (Gein.)

The Arenig cherts are thus associated here with the black shales, and though no well-marked zonal forms occur in this list of fossils, which evidently includes species common to both groups (Glenkiln and Hartfell), there can be little doubt that a portion of the band so well developed in the Polmorlach Burn is here represented.

Polhote Burn.—About half a mile to the south-east of the Polmorlach Burn, confirmatory evidence is obtained of the occurrence of a black shale which contains Glenkiln fossils and passes upwards into blue and grey shales, with dark seams resembling the beds in Polmorlach Burn. On the west branch of the Polhote Burn, a tributary of the Nith, an excellent section may be seen of the grey and blue shales with dark seams, all dipping to the S.S.E., from which the following forms, representing the Lower Hartfell horizon, were obtained: *Dicellograptus Forchhammeri*, *Diplograptus*, *Climacograptus*, and *Cryptograptus tricornis*. About 200 yards west of the fork, and 30 yards above the bend in the west branch of the Polhote Burn, where it flows nearly east and west, an outcrop of black shales associated with greywackes represents the Glenkiln horizon, and resembles lithologically the Glenkiln Shales in Polmorlach Burn and the Glenkiln black shales in Back Burn near Corsebank, Crawick Water. Graptolites occur here freely, and in excellent preservation: in particular, *D. superstes* and *C. Schärenbergi*. *Cœnograptus pertenuis* is also very abundant. The subjoined list gives the species collected at this place:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Glossograptus Hincksi (Hopk.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *moffatensis* (Carr.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Acrothele granulata (Linnr.)

At the bend in the stream just referred to, a band of pebbly grit, resembling a "Haggis Rock," is exposed on the right bank. The Glenkiln black shales reappear on the left bank, probably on a fold, and further down the stream displays a fine section of the flaggy blue and grey shales with dark seams, associated occasionally with greywackes. These rocks continue all the way down to the edge of the Carboniferous basin.

DALMELLINGTON DISTRICT.

Arenig Rocks along the Margin of the Silurian Tableland.

Along the margin of the Silurian Tableland in the neighbourhood of Dalmellington, a narrow strip of radiolarian cherts, with occasional exposures of the underlying volcanic rocks, is traceable for a distance of about five miles. It is about a quarter of a mile in breadth, and on the published map (Sheet 14) has

been coloured as part of the Old Red Sandstone formation. On the north side it is bounded by the fault which limits the Lower Old Red Sandstone, and on the south side it is truncated by the prolongation of the Glen App fault.

At the north-east end of this strip, the red cherts and mudstones are visible in a small knoll, near the sheep-ree about half a mile E.N.E. of Mossdale Farmhouse. Here they are pierced by a dolerite dyke running W.S.W. and E.N.E. In a little side stream, named the Trough Burn, about 400 yards east of Mossdale, the red cherts and mudstones occupy the watercourse for a short distance, rising from underneath the grey mudstones of the "Tappins group."* They also form small knolls on the north bank of the stream. The fault which truncates the red cherts and mudstones on the south side is visible in the Trough Burn. Further south in this stream, the strata exposed consist of shaly greywackes and shales. The fault that bounds the red cherts and grey mudstones on the north side is exposed in the Mossdale Burn, about half a mile above Mossdale. Here the grey mudstones are brought into conjunction with an intrusive felsite, the rocks on both sides being much shattered. To the north-east of this point, it is probable that the red cherts and mudstones extend for some distance, since numerous fragments of cherts occur in the drift.

In Glen Muck, just south of Mossdale Bridge, the green mudstones overlying the red mudstones occupy a strip about 150 yards broad. At the bridge across the Muck an exposure of lower old Red conglomerate is seen in a quarry, but the fault which brings the conglomerate in contact with the mudstones is not visible. On the south side these green mudstones are succeeded by the greywackes and shales of the Mossdale Craigs.

South-westwards along the margin of the Silurian area, the rocks are concealed under drift for some distance. The cherts reappear, however, in a small burn that drains into the Doon below the Glen of Ness, near Dalfarson. At a point in this burn about half a mile from its junction with the Doon, about two feet of a porphyritic slaggy lava (Arenig) may be detected in the midst of the red cherts. The rock is purple, contains much decomposed porphyritic felspar, and resembles externally some of the Arenig porphyritic lavas at Ballantrae. About 70 yards north from this small exposure, another small mass of Arenig lava which appears in the slope, is like the ropy lava about a mile to the south-west of Berbeth. Various knobs of red cherts and red mudstones are to be found on the south slope of the Well Hill. At one point the red mudstones occur not far from the Lower Old Red Conglomerate, the position of the fault between the two being indicated by a well-marked feature. The Old Red Conglomerate is vertical, and its pebbles are composed almost wholly of greywacke.

* This term is applied to a group of strata, which, at Portandea, north of Glen App and in the valley of the Stinchar above Barr, overlie conformably the Arenig cherts and volcanic rocks.

Berbeth to Knockdon.—South-westwards from the Ness at Dalfarson to Knockdon, on the river Girvan, several exposures of the Arenig cherts may be observed associated at one locality with characteristic lavas. The red cherts and mudstones are to be seen in the policies of Berbeth, on the east side of the mansion house, where they form a prominent knoll. They are visible also in the Glessel Burn, to the south of Berbeth. In this stream up to the waterfall above the old gasworks, shattery grey mudstones and greywackes are laid bare which resemble the "Tappins group" of the Stinchar valley. The red cherts and mudstones reappear, however, on another fold three-quarters of a mile south-west of Berbeth Mansion-house, near a prominent bend of the Glessel Burn. The crags about a quarter of a mile to the south-west of Berbeth display a fine development of shattery green and grey mudstones and greywackes of the "Tappins series." It is obvious that the section along this part of the margin of the Silurian Tableland bears a close resemblance to that in the Stinchar valley near the Tappins (see p. 464).

Still further to the south-west, in one of the branches of the Glessel Burn, fed by streamlets which drain the northern slopes of the Big Hill of Glenmount, about a mile from Berbeth Mansion-house, red and grey cherts and mudstones are laid bare, succeeded northwards by green mudstones and greywackes, seen at intervals in the stream, the general dip being to the south-east.

In the same south-westerly direction, green and grey mudstones and greywackes are exposed in several knobs, with an occasional outcrop of red cherts and mudstones. On the slope, immediately to the north of the Wee Hill of Glenmount, and not far from the alluvial flat formed by one of the branches of the Glessel Burn, a section shows the relation of the Arenig volcanic rocks to the cherts. The lavas are seen in several knobs, bounded on the north side by the red cherts and mudstones. In one of these exposures, where the rock is less decomposed, it is vesicular, and contains porphyritic felspars set in a dark micro-crystalline matrix, and shows traces of the pillowy structure already noticed. To the south of this mass a pink intrusive igneous rock occurs, which is largely developed in the immediate neighbourhood to the north. The red cherts and red mudstones can be followed south-westwards at intervals to near the Knockdon Craig, which is the last exposure of them to be met with in the direction of the Girvan valley.

It might be contended that some of these red cherts and mudstones, formerly mapped as part of the Lower Old Red Sandstone, may have been stained by the members of the Old Red Sandstone which formerly covered them. But such a supposition is improbable, because the Old Red Conglomerate immediately in contact with the cherts is grey in colour and charged with greywacke pebbles. It is further of interest to note that the acid intrusive rock which pierces the Arenig cherts and the overlying mudstones and greywackes south of the Wee Hill of

Glenmount is identical in character with that which cuts the Lower Old Red Sandstone strata to the north. It also bears a close resemblance to the acid intrusive rocks which surround the Criffel and Dalbeattie granite mass.

The fault that bounds the belt of Arenig cherts and overlying mudstones between Knockdon and Glen Muck can be of no great magnitude, because the conglomerate in contact with the Arenig rocks is apparently the basal conglomerate of the Old Red formation which throughout Ayrshire is composed mainly of greywacke pebbles.

Connel Burn to Benty Cowan Hill (south-west from New Cumnock).—About a mile from the margin of the Silurian Tableland west of the Afton, the Arenig volcanic rocks and radiolarian cherts and mudstones come to the surface along another line which stretches from the Connel Burn to Benty Cowan Hill (Sheets 14 and 15 of the Survey Map), a distance of about one and a half miles. The Arenig cherts are not traceable the whole distance, being succeeded by pebbly greywackes and grits along the line of strike.

Ascending the Connel Burn from the point where it is crossed by the fault that brings the Carboniferous rocks into contact with the Silurian strata, we find two outcrops of pebbly grit or "Haggis Rock" inclined to the south-east. Not far to the south of these exposures, the cherts and mudstones are to be found on two folds; the more northerly one shows only red cherts and mudstones on both banks of the stream, succeeded immediately by greywackes; in the second fold, visible in a streamlet on the east bank of the Connel Burn, the red, green, and grey cherts are met with.

Along the line of strike to the south-west of the Connel Burn, volcanic agglomerate crops out on the Connel burn Rig, at a point about 500 yards from the exposures of the cherts in the Connel Burn. This rock forms small rounded knobs on the hill slope, and at one spot there is a small opening as if it had been quarried. The rock is decomposed, but it seems to have a fragmental matrix of crystalline igneous material, through which are scattered fragments of black, red, and grey cherts. In a little grass-covered opening, which may have been a small quarry, the red cherts are seen in contact with the volcanic rock. They are also visible in drains on both sides of the agglomerate. About 40 yards down the slope pebbly grit of the "Haggis Rock" type, with mudstones, appears in a small scar.

South-westwards along the hill slope, at a distance of a quarter of a mile, various exposures of the radiolarian cherts may be observed above the level of the 1250-feet contour line; and on the crest of the ridge between the Connel Burn and the Blarene Burn, small knobs of vesicular basaltic lava of Arenig age are seen peering through peat. About a mile still more to the south-west, the red cherts crop out on the slope of the Benty Cowan Hill, along a fold which must lie slightly to the north of the strike of the arches referred to in the foregoing paragraphs.

A noteworthy feature in connection with the exposures of Arenig volcanic rocks and cherts between Connel Burn and Benty Cowan Hill, is the absence of the peculiar mudstones and greywacke bands of the "Tappins group" in the Stinchar valley. Representatives of that series, as already indicated, crop out near Berbeth in association with the radiolarian cherts at the margin of the tableland. Their absence here may indicate a slight unconformability; at anyrate, the "Haggis Rocks," which rapidly succeed the cherts in the Connel Burn, contain abundant fragments of chert and fragmental material derived from the disintegration of volcanic rocks.

Beyond the watershed the Dalleagles Burn, on the west side of Benty Cowan Hill, has laid open a good section of well-bedded flaggy shales and greywackes, dipping generally to the south-east. These beds resemble those seen in part of Glen Muck.

Pochriegavin Burn.—About a mile to the south of the strike of the Connel Burn and Benty Cowan Hill band of radiolarian cherts and mudstones, another anticlinal fold which reveals the cherts and overlying black shales with graptolites, is traceable for about a mile from the Pochriegavin Burn, a tributary of the Deugh, north-eastwards to a small stream which drains the south slope of the Stony Knowes Hill. About 300 yards to the west of the point where the Prickeny Burn joins the Pochriegavin Burn, grey cherts with radiolaria appear in the bed of the latter stream, with dark blue shales on the south side. The shales, though crushed, yield fragments of graptolites. The general dip is to the south-east. Higher in the stream, in the intervals between gaps in the section, occasional exposures of flaggy grits, greywackes, and shales may be seen; till at a point about 150 yards west of the radiolarian cherts, flaggy dark blue and grey shales, finely striped with dark seams with fragments of graptolites are met with. In dark blue sandy shales exposed in the bed of the stream, the following fossils were obtained:

Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)
Dicellograptus sp.
Corynoides calycularis (Nich.)
Lasiograptus margaritatus (Lapw.)

In a small burn that drains the Stony Knowes Hill and joins the Pochriegavin Burn about half a mile north-west of Lochmaharb shepherd's house, the radiolarian cherts appear about 200 yards from the foot of the streamlet. The grey cherts are first seen where a fence crosses the burn. A few yards further north the grey cherts are typically developed, and enclose abundant radiolaria. They are associated with mudstones and dark blue shales, the latter occurring in two synclinal folds. Again on the north side of the cherts, after an interval of several yards, grey sandy shales are met with, followed by greywackes and shales.

The zonal graptolites characteristic of the Glenkiln Shales have not been obtained as yet from the beds in immediate contact with the cherts of the Pochriegavin band, the dark blue

shales next the cherts being too much crushed to yield graptolites in that stream. About a mile to the south, however, on another anticlinal fold, a section in the Deugh of part of the Moffat series, has furnished a large suite of graptolites. This section closely resembles that in Polhote and Polmorlach Burns in Sheet 15, north-west of Sanquhar (p. 368).

CARSPHAIRN DISTRICT.

Black Shale Bands in the Basin of the Deugh Water.

Hillend, Water of Deugh (Sheet 14 of the Survey Map).—On the east bank of the Deugh, about 500 yards south of the mouth of the Pochriegavin Burn at the shepherd's house of Hillend, the graptolite-bearing beds are exposed at intervals for a distance of about 60 yards. The fossils obtained at one point in the section show that the strata belong to the Glenkiln group; but it is probable that some of the other bands, yielding forms common to the Glenkiln and Hartfell groups, may be the passage beds between these two horizons.

The north end of the section presents alternations of grey and dark blue or black shales, finely striped, in a band of black shales alternating with the grey seams, from which the accompanying list of fossils was obtained:

Dicranograptus ramosus (Hall.) var. *spinosus* (Lapw.)	*Climacograptus* sp.
Dicellograptus sextans (Hall.)	*Cryptograptus tricornis* (Carr.)
,, *Forchhammeri* (Gein.)	*Dicranograptus ramosus* (Hall.)
Leptograptus flaccidus (Hall.)	*Diplograptus foliaceus* (Murch.) abundant in some of the seams.

About twelve yards down stream on the same bank, dark blue or black shales, alternating with greywackes, contain *Dicranograptus ramosus* abundantly in certain layers, *Cryptograptus tricornis* abundantly, *Climacograptus Schärenbergi*, and *C. bicornis*. Lower, on same bank, in black sandy shales, *Dicranograptus ramosus* and *Cryptograptus tricornis* have been found abundantly; also *Diplograptus foliaceus*, *Dicellograptus sextans*, and *Corynoides calycularis*.

At a point on the east bank about 54 yards below the first exposure, black or dark blue flags or shales afford graptolites characteristic of the Glenkiln group in abundance and fine preservation. The lithological characters of the Glenkiln Shales, as here developed, differ widely from those in the typical Moffat region. Instead of alternations of black cherty ribs and black shales, flaggy dark blue or blue-black sandy shales occur here, like the band of Glenkiln Shale in Polhote Burn north-west of Sanquhar. The fossils are well defined, but owing to the presence of iron pyrites in the shale they ultimately disappear. The following list was here obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Climacograptus Schärenbergi (Lapw.)
,, *peltifer* (Lapw.)
Dicranograptus ramosus (Hall.) var. *spinosus* (Lapw.)
Dicellograptus sextans (Hall.)
Diplograptus foliaceus (Murch.)

On the same slab with *Climacograptus peltifer* occur *Dicellograptus sextans*, *Dicranograptus ramosus*, and a fragment of *Cœnograptus pertenuis* and *Climacograptus Schärenbergi*. Minute seams of grey shale are interleaved in the foregoing black flaggy shales. Down stream greywackes appear, with alternations of dark shales seamed with grey shales. From the manner in which bands of greywacke are intercalated in these graptolite-bearing shales, it is probable that the Glenkiln or Upper Llandeilo Rocks are here partly represented by graptolite-bearing shales and partly by greywackes.

Petillery Hill.—About half a mile to the south of the graptolite bands just described, grey cherts with radiolaria appear in association with greywackes and grits on the west slope of the Petillery Hill, on the east side of the valley of the Deugh. They form a series of rocky knolls peering through heather and turf, named on the six-inch map (Kirkcudbright 2, S.W.) the Shiel Knowes. The peculiar feature of these exposures is the alternation of grey radiolarian cherts with bands of greywacke, which measure in some instances several feet across. At one spot the rock next the chert is a grit with minute fragments of radiolarian chert. No graptolite shales are associated with the cherts at this locality.

Brownhill Burn.—At the point where this stream joins the Deugh, in the bed of the latter stream, black shales with grey seams and red cherts are exposed, which can be traced for a short distance down the river when the stream is low. On the west bank the strata are pierced by a dyke of porphyrite.

Not far from the foot of the Brownhill Burn, and a few yards south of the footbridge, crushed and shattery black shales are intercalated in blue shales. Graptolites are abundant in certain layers, and though the shales are very shattery the fossils are in good preservation. The following Glenkiln forms were obtained:

Dicranograptus ramosus (Hall.) var. *spinosus* (Lapw.)
Diplograptus mucronatus (Hall.)
,, *foliaceus* (Murch.)
,, *euglyphus* (Lapw.)
Diplograptus perexcavatus (Lapw.)
Lasiograptus bimucronatus (Nich.)
Cryptograptus tricornis (Carr.)
Climacograptus sp.
Dicellograptus sextans (Hall.)

About 150 yards further up stream, in flaggy dark blue shales, among other forms *Climacograptus bicornis*, *Diplograptus foliaceus*, and *Dicellograptus* were found. In a small stream that joins the Brownhill Burn on the west side (the Polgavin Burn), black shales occur. No fossils except graptolite fragments were here obtained,

Knockingarroch (Water of Deugh, Sheet 8 of Survey Map).—About a quarter of a mile below Knockingarroch, and

about two miles north of Carsphairn, black shales which yield a fine assemblage of Glenkiln graptolites are laid bare in the Water of Deugh. At the southern limit of the section, on the east bank of the stream, grey and dark blue shales are interstratified with thin leaves or seams of black shales, an eighth of an inch thick, which yield traces of graptolites mostly indeterminable. These beds, occupying about 12 yards of the section, are succeeded by shattered black shales, certain bands of which yield graptolites in profusion, including *Dicellograptus sextans*, *Lasiograptus bimucronatus*, *Diplograptus mucronatus*, *D. foliaceus*, *D. perexcavatus*, and *Cryptograptus tricornis*. Northwards these black shales are followed by blue flags, shales, and greywacke bands, which, after a blank, are in turn succeeded by a fine development of black shales, visible on the eastern bank and in the bed of the stream. The platy shales are crowded with graptolites, some of the seams yielding well-preserved specimens of zonal forms of the Glenkiln group, the examples of *Didymograptus superstes* being especially perfect. A few yards up stream, on the east bank, gritty greywacke is observable, but no continuous section to the north or south of the foregoing black shales reveals their relation to the overlying sediments.

Bridge-End.—Not far above the bridge across the Deugh, about a mile north of the village of Carsphairn, black shales much crushed and shattered are visible, where they dip to the east of south, on the left bank of the stream, and are succeeded by blue greywackes.

Garryhorn, Cairnsgarroch, and Carlin's Cairn.—A series of compound folds of the Moffat series and associated sediments in the neighbourhood of the Woodhead Lead Mines, west of Carsphairn, is specially interesting, from the contact metamorphism superinduced on the radiolarian cherts by the Loch Doon granite mass. It exhibits a further notable feature in the marked deflection of the strike of the beds as they approach the margin of the igneous mass. For example, in the Garryhorn Burn, the strike of the strata is, generally speaking, about E.N.E., but traced westwards to the slope of the Kells range, it is deflected to the S.S.W., and runs roughly parallel with the granite boundary for several miles. Owing to contact metamorphism, many of the exposures are of little service in determining stratigraphical horizons by means of fossils; certain sections, however, prove that the Arenig cherts are succeeded by black shales yielding Glenkiln graptolites, and that the highest fossiliferous zone underlying the Carsphairn grits and conglomerates belongs to the Lower Hartfell black shales.

The Garryhorn Burn above its junction with the Halfmark Burn flows over a series of greywackes and shales, with grits and fine conglomerates, till at a point about 150 yards south-east of Garryhorn Farmhouse Arenig cherts and black shales make their appearance. Here the grey nodular and banded cherts are crowded with radiolaria. On the south limb of the fold, the black shales, with a south-east dip, enclose the following Glen-

kiln forms: *Cœnograptus pertenuis*, *Dicellograptus sextans*, *Climacograptus bicornis*, *C. peltifer*, *Lasiograptus bimucornatus*, *Diplograptus foliaceus*, *D. euglyphus*, *Acrothele*, &c. A few yards further down stream, on the same side, shattered and brecciated black shales occur, containing graptolites in some of the jointed masses. Here *Corynoides calycularis* appears in profusion in some of the seams, together with *Siphonotreta micula*. Further down on the north side of the burn, and a few yards above the footbridge, the Glenkiln black shales reappear, charged with *Didymograptus superstes*, *Cryptograptus tricornis* in profusion, *Dicranograptus ramosus*, &c. A fault traverses the bed of the stream at this point, the direction of which is indicated by fault-breccia. On the north limb of the fold, shattered black shales appear, but too much crushed to yield graptolites.

About 400 yards south-west of Garryhorn Farmhouse, the Arenig cherts and black shales appear, the latter being considerably crushed and corrugated. On the south limb of the fold, the black shales on the north bank yielded *Diplograptus euglyphus*, *D. foliaceus*, *Dicranograptus ramosus*, *Cryptograptus tricornis*, *Climacograptus*, *Dicellograptus*, and *Corynoides*. Still further west, at the lower end of the alluvial flat below the Woodhead smelting-houses, radiolarian cherts crop out, but their relations to the surrounding rocks are not visible. About 130 yards to the south of them, the following graptolites were obtained from debris of black shale lying near an old trial pit: *Diplograptus foliaceus*, *Dicranograptus*, *Climacograptus*, *Corynoides calycularis*, &c. The surfaces of some of the slabs are crowded with specimens of the last-named form.

In the strike of this series of compound folds, the Arenig cherts and black shales appear on the Black Craig, which forms the termination of the north-eastern spur of the Cairnsgarroch Hill. The latter eminence lies on the south side of the Garryhorn Burn, and two miles south-west of Woodhead Lead Mines. The north-east face of this crag exposes the black shale series. A small outcrop of the cherts is faulted on the south side against greywackes and pebbly grits. Northwards black flinty ribs, with thin partings of black shales, succeed, which afford *Cœnograptus gracilis*, *Lasiograptus bimucronatus*, *D. foliaceus*, *Dicellograptus sextans*, *Climacograptus bicornis*, and *Cryptograptus tricornis*. At the top of the crag, due west of the arch of cherts, the black shales yield *Dicranograptus ramosus* in abundance.

Further to the south-west the radiolarian cherts reappear, and are truncated on the south-east side by a fault which brings them in contact with the overlying greywackes and shales. On the north-west side they are followed by corrugated black shales, the junction between the two groups being a line of fault. The only fossils obtained from these twisted bands are *Corynoides calycularis*, *Diplograptus foliaceus*, and *Climacograptus Schärenbergi*.

Three-quarters of a mile to the south-west a broad exposure of the Arenig cherts, black shales, and overlying sediments rises into a prominent crag on the north slope of Cairnsgarroch Hill,

about two miles to the south-west of Woodhead Lead Mines. This declivity is drained by two streams, of which the most westerly one is named on the six-inch map, the Lumps Burn. About 200 yards east from this streamlet, and near the centre of the section, a well-marked arch of radiolarian chert, though

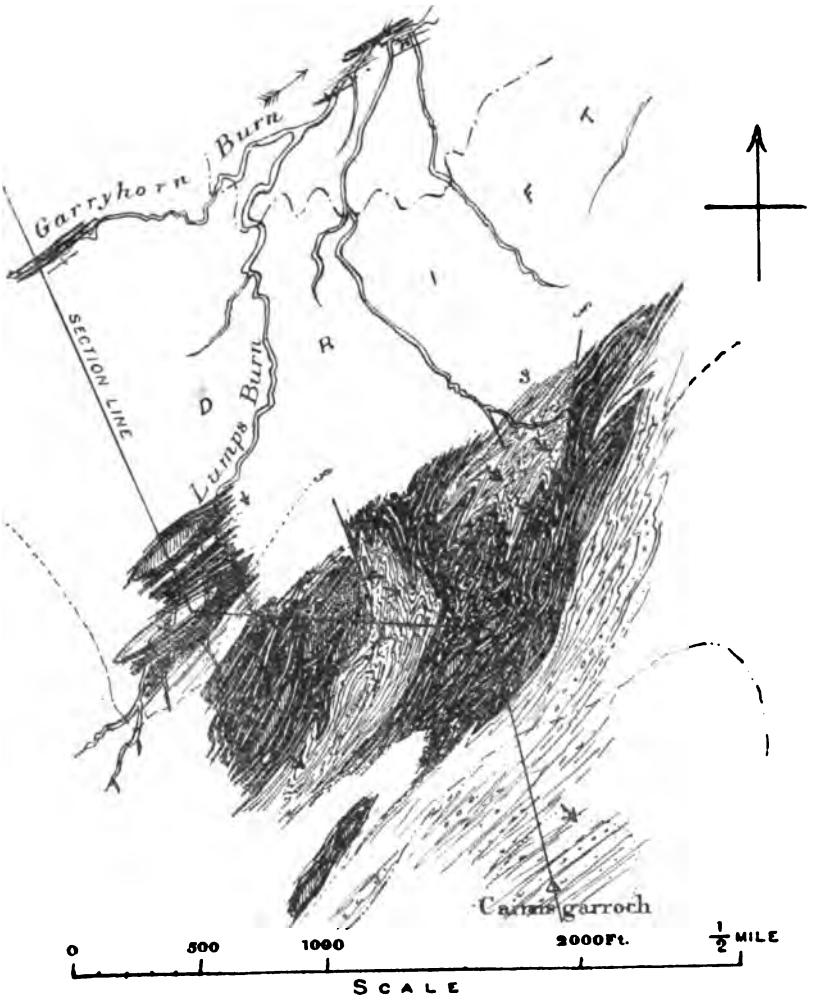


FIG. 92.—Plan of Strata in Crag, Cairnsgarroch, Carsphairn.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Lower Hartfell Shales. 3. Greywacke and shale (Caradoc). ⌒ Boulder clay. ≈ Moraines. f. Fault.

about a mile distant from the granite boundary, is slightly granulitised. The black shales and dark flinty ribs near the cherts on the north-west side yield *Lasiograptus bimucronatus*, *Cryptograptus tricornis*, *Dicranograptus ramosus*, and *Dicellograptus*. About ten

yards from the cherts, on the same side, the following forms were obtained, viz.: *Dicranograptus ramosus*, *Climacograptus bicornis*, and *C. tridentatus*; while at a distance of 45 yards *Dicellograptus* and *Dicranograptus* are found crowding the slabs of black shale, together with *Climacograptus Schärenbergi* and *Diplograptus foliaceus*—forms which indicate the basal zones of the Lower Hartfell black shales.

On the south-east limb of the arch, the cherts are brought by a fault immediately into contact with the overlying grey sandy shales of Lower Hartfell age. The relations of these sandy shales to the black shales are clearly defined in the eastern portion of this crag (see ground plan, Fig. 92, Section Fig. 93, and one-inch Geological Map, Sheet 8), for as we proceed eastwards along the escarpment we find an arch of black shales running up the slope to the top of the crag and plunging underneath the grey sandy shales to the north-east and south-west. In the seams of black shale immediately in contact with the grey sandy shales, a characteristic assemblage of Lower Hartfell fossils was obtained. Beautiful examples of *Dicranograptus Nicholsoni* (wide-angled variety) were collected, and near to this locality the slabs of black shales are crowded with well-preserved shells. Moreover, in thin leaf-like seams interleaved in the overlying grey sandy micaceous shales, *Climacograptus bicornis*, *Dicellograptus*, and *Diplograptus foliaceus* occur, which indicate a natural passage upwards from the lower zones of the Hartfell black shales into the coarser shaly sediments and overlying pebbly grits and conglomerates.

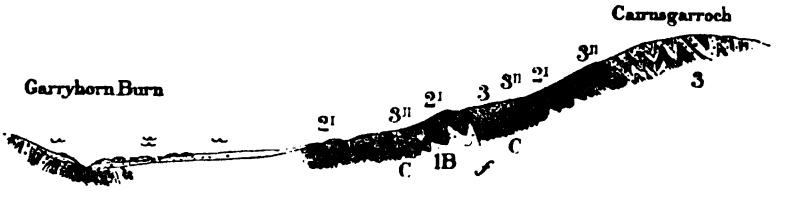


Fig. 93.—Section of Crag, Cairnsgarroch, Carsphairn, along the line marked in Fig. 92.

Eastwards along the crag, the grey sandy shales are abruptly truncated by a fault which brings them in contact with the black shales and cherts to the south-east. Disregarding minor flexures, it is obvious that, on Cairnsgarroch Crag, the Arenig cherts and black shales come to the surface along two main anticlines, and that the grey sandy shales lie in small intervening troughs.

These outcrops of the Moffat series are traceable south-westwards to the southern slopes of the Meaul (2279 feet) and the head-waters of Pulmaddy Burn, where highly corrugated and granulitised cherts are associated with black shales which still yield graptolites. In a tributary of the Goat Burn, that drains the south-east slope of the Meaul, an outcrop of black shales

yielded the following Glenkiln forms: *Didymograptus superstes*, *Dicranograptus minimus*, *D. ramosus*, *Dicellograptus sextans*, *Diplograptus perexcavatus*, *D. foliaceus*, and *Cryptograptus tricornis*. Graptolites are, however, difficult to obtain within half a mile of the granite, and they disappear close to the boundary line. Perhaps the finest examples of the extreme alteration of the Arenig cherts are to be found in the band (Sheet 8 of the Map) which has been traced along the western slope of the Meaul for a distance of a mile and a half close to the margin of the granite.

Half-mark Burn and Craigchessie.—Rather less than half a mile to the south-east of the Cairnsgarroch band of black shales, another outcrop of the Moffat series is distinguished by the presence of certain zonal Hartfell graptolites in the shales that underlie the sandy shales and conglomerates of that region (Carsphairn Grits). On the eastern slope of Cairnsgarroch Hill, three rivulets unite to form the Half-mark Burn. Near the head of the middle streamlet, abundant debris of black shale occurs, which affords graptolites in good preservation: *Diplograptus euglyphus*, *D. foliaceus*, *Climacograptus peltifer*, *Dicranograptus ramosus*, *Cryptograptus tricornis*, *Acrothele granulata*, &c. On the slope above, the Arenig cherts appear, but unfortunately owing to the covering of turf the prolongation of their outcrop is concealed from view for some distance to the north-east and south-west. The members of the Moffat series reappear, however, about a mile to the south-west, on Craigchessie, which forms the southern spur of Cairnsgarroch. Here the cherts, including the black and grey, nodular and ribbed varieties, come to the surface on an isoclinal fold. Near the 1850-feet contour line they dip E. 40° S., and further down the slope the direction is E. 20° S. Debris of black shale occurs underneath the turf close to the cherts, but owing to the covering of vegetation the Glenkiln black shales do not appear at the surface. At the 1500-feet level, however, on the south-east limb of the arch, a dry gully within a few yards of the radiolarian cherts displays a fine section of the lower zones of the Hartfell black shales. Some of the slabs are crowded with *Dicellograpti* to the exclusion of any other form, and some with *Diplograptus foliaceus*. The following additional forms were noted, viz.: *Amphigraptus radiatus*, *Dicellograptus Morrisi*, *Climacograptus caudatus*, and *Dicellograptus Forchhammeri*.

The evidence now adduced regarding the exposures of the Moffat series in the neighbourhood of Cairnsgarroch and Garryhorn Burn indicates an ascending sequence from the Arenig cherts and Glenkiln-Hartfell black shales to the shales, grits, and conglomerates of the Carsphairn region.

Sediments mainly of Caradoc Age overlying the Glenkiln-Hartfell Black Shales between the Nith and the Loch Doon Granite Mass.

Reference must now be made to certain sediments which overlie the various folds of the Arenig cherts and Glenkiln-

Hartfell black shales to the north of the Llandovery base-line, within the tract that extends from the Nith to the Loch Doon granite mass. The evidence adduced in the foregoing pages shows that in the arches of the Moffat series, extending from Burnmouth on the Nith to Dalshangan on the river Deugh, the Lower Hartfell black shales of the *Dicellograptus Clingani* zone still present the same general lithological characters as those in the Moffat region, where they consist of platy black shales. But when they are followed northwards to the Polmorlach and Polhote Burns, within two miles of the northern margin of the tableland at New Cumnock, this lithological type has disappeared, and the lower zones of the Hartfell black shale group are represented by thin black seams interleaved in blue and grey shales. Still further north, along the Silurian border, the Hartfell shales are no longer traceable, and in the region near Loch Muck, to the north-west of Carsphairn, the Glenkiln graptolites occur in dark shales embedded in grey shales and greywackes.

When these facts are taken into consideration, it is reasonable to infer that the coarse sediments between the Nith and the Loch Doon granite mass are mainly of Caradoc age, as they overlie some members of the Hartfell black shales throughout the greater part of the area. At the same time it is highly probable that some of the greywackes and shales which are intercalated in the graptolite shales that yield Glenkiln forms may be of Upper Llandeilo age.

The sediments now under consideration, the age of which cannot be definitely ascertained by means of fossils derived from the beds themselves, consist of (1) massive conglomerates, (2) black grits and greywackes with pebbly bands, (3) zones of flagstones and shales with occasional limestone nodules and bands of grit or conglomerate. These subdivisions are well seen in the tract between the Nith and the Kells Hills.

The group of flagstones and shales with limestone nodules are repeated by folds throughout the area, but are specially well seen in the river Nith between Enterkinfoot and Burnmouth, in the lower portion of the Burnsands Burn, in various slate quarries in the Dalwhat Valley, and also at the junction of the Deugh with the Ken. It is not improbable that as the flagstones and shales pass northwards from the Llandovery base-line across the successive anticlines of the Moffat series, they may occupy a slightly lower geological horizon than that of the Barren Mudstones of Moffat.

Prominent among these overlying sediments are the conglomerates of the Shinnel and Afton Waters. The Shinnel group is traceable from the Shinnel valley north-eastwards into those of the Chanlock and the Scar. The coarse conglomerates shade into pebbly grits and greywackes with thin shaly partings; the included pebbles, which are embedded in a greyish gritty matrix, sometimes calcareous, vary from the size of a pea to a foot in diameter. The blocks are well rounded, and consist of acid and basic intrusive igneous rocks, slaggy diabase-lavas (Arenig),

radiolarian chert, black and grey varieties, blue and grey greywacke, grey shale, black shale, quartz, &c. From the fragments of black shale in the conglomerate of the March Burn, two small graptolites were obtained, one probably a *Diplograptus*, and the other a *Climacograptus*. From the same place *Orthis calligramma* and remains of encrinite stems, probably *Glyptocrinus*, were procured—forms which occur in the Duntercleuch conglomerate of the Leadhills region. Further palæontological evidence is supplied by the dark shales associated with the pebbly grits and fine conglomerates of this series, which yield imperfectly preserved graptolites. For example, in the Kirkconnell Burn—a tributary of the Shinnel from the west—a specimen of *Climacograptus* of Llandeilo type was found in black shales and dark grit, about 300 yards from Cormilligan shepherd's house, and to the north of a band of conglomerate (Sheet 9 of the Survey Map). Again, in the Glenskelly Burn—a tributary of the Dalwhat Water, about three miles north-west of Moniaive—graptolites of Caradoc types were obtained. In the middle branch of this stream, about 900 yards above Dalwhat House, dark blue or grey shales, with black seams or leaves about an eighth of an inch thick, yielded *Leptograptus flaccidus*, *Dicellograptus elegans*, *Diplograptus foliaceus*, and *Climacograptus bicornis*. Similar palæontological evidence was afforded by the Corrodow slates, at a point about four miles north-west from Moniaive in the Dalwhat valley. Again, at the sheep-stell, in the Kirkconnel Burn, about a quarter of a mile south of Cormilligan, blue shaly mudstones and shales contain limestone nodules and oval masses of grit, about two feet across. One of the limestone nodules yielded a coral. Where a stone fence crosses the stream, the shales are slightly stained, and some of the bands have a silky texture.

Though the palæontological evidence regarding the age of the Shinnel Water conglomerate is not very definite, it nevertheless furnishes reasonable ground for assigning this rock to the Caradoc rather than to the Llandovery formation. The recurrence of zones of grey shales with black strains containing Caradoc graptolites between Clodderoch Burn (Shinnel Water) and Corrodow (Dalwhat Water) points to the conclusion that the associated strata are of the same age. But while this is doubtless a reasonable inference, it ought to be frankly admitted that some of the massive grits lying to the north of the line which has been provisionally drawn as the base of the Llandovery Rocks resemble the Llandovery grits, and may be of the same age. Examples of these grits occur in the Barlae Hill, three miles north of Dalry; but even there, the fossil evidence supplied by the flaggy shales in the Barlae Quarry is opposed to the reference of them to the Llandovery formation, for in the flaggy shales of this quarry the worm tracks long ago recorded by Professor Harkness are associated with *Diplograptus foliaceus* and *Climacograptus*.

An outcrop of fossiliferous conglomerate appears in the

Pulharrow Burn, about a mile below its junction with the Burnhead Burn. It contains pebbles of fine-grained limestone, granulitic quartz-schist, grit, and fragments of black shales; some portions of the rock are highly calcareous, and yield encrinites, shells, &c. (Sheet 8 of the Map).

Far to the north-west, at the head of the Afton Water (Sheet 15), this conglomeratic series is prominently developed on both sides of the valley between Craigdarroch and Montraw, where its beds dip to the N.N.W. at high angles. The pebbles, which are well rounded, lie in a matrix of grey grit, and vary in character in different layers. The largest boulders consist of granite and greywacke. One of grey granite was found to measure three feet by one foot and a half, and another 18 inches by six inches, while some of the greywacke pebbles measure two feet in diameter. The following percentage of included blocks was taken on the moor about a mile south-west of Craigdarroch, on the way to Montraw:

Gabbro, banded and other varieties, and dolerite, ...	22	per cent.
Grey felsitic rock, ...	27	,,
Granite, ...	10	,,
Greywacke, ...	10	,,
Diabase-lava, ...	6	,,
Intrusive felsite, ...	4	,,
Limestone, ...	7	,,
Shale, ...	4	,,
Chert, ...	9	,,
Quartz, ...	1	,,
	100	,,

Another outcrop of conglomerate on the south slope of Auchincally Hill, two miles west of the Afton Water, is traceable southwestwards to the head-waters of the Deugh. One of the best exposures (south-east corner of Sheet 14) is to be seen on the east slope of Hillend Hill, about a mile north of Hillend, where the lithological characters of the rock are similar to those of the Afton Water conglomerate just described. A fine section of highly inclined or vertical beds of massive grits, greywackes, and shales is also met with on the west slope of the neighbouring Craignane Hill. The slope is bare of drift, and the observer can see to advantage the massive character of the sediments. No fossils have been found in the conglomerates or grits of the Afton or Deugh Waters, but these rocks lie to the south of the strike of the thin seams of black shale in the Polmorlach and Polhote Burns, which yield graptolites belonging to the lower zones of the Lower Hartfell black shales.

Again, in the Carsphairn district, well-marked conglomerates and pebbly grits occupy synclinal folds of the Moffat series, as, for example, on the Craig of Knockgray, N.N.E. of Carsphairn, on the Cairnsgarroch Hill, on the Meaul and Carlins Cairn in the Kells range, south-west of the Woodhead Lead Mines (Sheet 8). Here there is a similar assemblage of pebbles, though perhaps in slightly different relative proportions. On

the eastern spur of Cairnsgarroch Hill, south of Woodhead Lead Mines, a pebble of quartzite several inches long, like that of the Perthshire Highlands, was found in the conglomerate. The conglomerates and pebbly grits appears to lie there in a trough of Arenig cherts and Glenkiln-Hartfell black shales, the highest zone represented being that of *Climacograptus caudatus* of the Lower Hartfell division.

A glance at the map that accompanies this volume will show that from the number of outcrops of the Moffat series in the broad track extending from the Llandovery base-line in the northern margin of the tableland, the coarse sediments now under consideration must be repeated by innumerable folds. It is true that over a belt of ground, about four miles in width, between the Polhote Burn west of Kirkconnell and the black shale bands south of the Euchan Water, no exposures have been detected which can without doubt be referred to the Arenig cherts or Glenkiln black shales. But even within this tract the Caradoc sediments may be highly folded, because along the strike of the strata south-westwards in the Carsphairn district, the Arenig cherts and overlying black shales repeatedly come to the surface.

CHAPTER XVIII.

THE NORTHERN BELT—*continued.*

ARENIG, LLANDEILO, AND CARADOC FORMATIONS IN THE DISTRICT BETWEEN THE MERRICK HILLS AND THE PORTPATRICK COAST-LINE.

THE detailed structure of the region lying between the Loch Doon granite mass and the Portpatrick coast-line is of considerable interest from the relation which it bears to the structure of the Ballantrae and Girvan region. Along the southern margin of the belt between Loch Trool and the Water of Luce, anticlines of the Moffat series display a sequence from the Arenig volcanic rocks and overlying cherts to the Glenkiln-Hartfell black shales; while on its northern margin, at Portandea and other localities north of Glen App, a similar succession from the Arenig volcanic rocks and overlying cherts to blue-black mudstones yields a characteristic assemblage of Glenkiln graptolites. Throughout the intervening area abundant evidence may be noticed of the lateral modification of the Glenkiln-Hartfell black shales and of the replacement of the Moffat types of sedimentation by deposits which accumulated nearer shore.

i. Black Shale Bands between Lamachan, near Loch Dee, and Dunragit, near Glenluce.

Not far to the north of the line which has been drawn as the base-line of the Llandovery Rocks of the Central Belt between the river Cree and the Water of Luce, a prominent series of axial folds of the Moffat series, though not all quite in the same line of strike, forms a well-marked feature on the map between Curleywee at the south-west corner of the Loch Dee granite mass and Gabsnout in the valley of the Luce (two miles N.W. from Glenluce)—a distance of about twenty miles.

Curleywee and Lamachan.—Beginning at the north-east corner of the belt, the observer finds a great development of cherts and black shales on the Curleywee and Lamachan Hills, on the south-west margin of the Loch Dee granite mass, where they form precipitous crags, which tower above long lines of debris. A glance at the Geological Map of the district (Sheet 8), shows how the members of the Moffat series are repeated by innumerable folds till the outcrop east of Lamachan Hill is about half a mile in breadth. Unfortunately, owing to the

contact metamorphism induced by the granite, these exposures are of little service for zonal classification, as the fossils have in most cases been destroyed. Few graptolites have been obtained in the prolongation of this band south-westwards towards the sources of the Cardorkin Burn, south of the Larg Hill. Two small outcrops of diabase-lava have been noted; one within the contact zone, on the precipitous crag about three-quarters of a mile east of the top of Lamachan Hill, where a

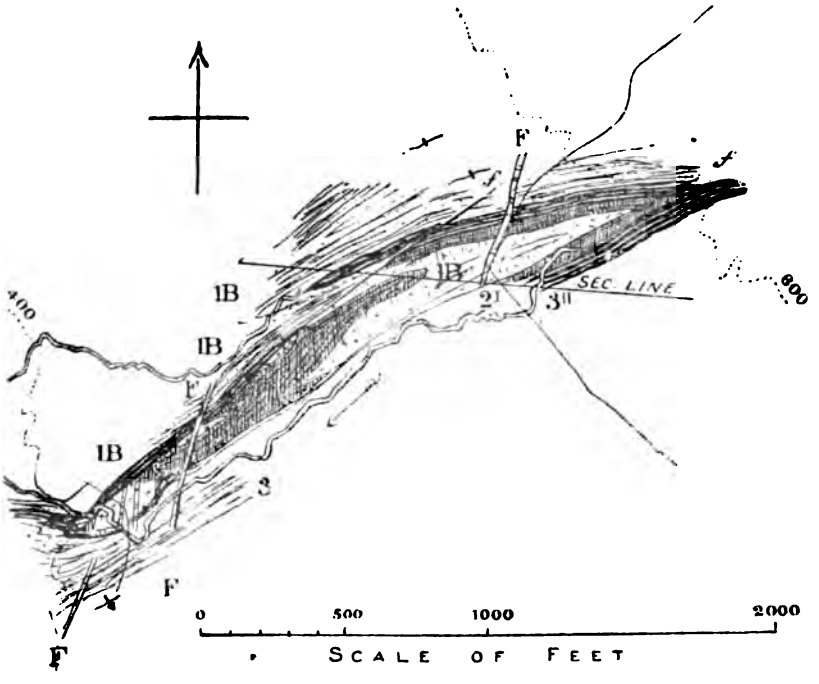


FIG. 94.—Plan of the Strata in part of Lagbaes Burn, Cardorkin, Kirkcudbrightshire.

1B. Arenig volcanic rocks. C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke and shale (Caradoc). F. Felsite dyke. f. Fault.

narrow band of lava, about fifty feet broad, forming the core of an arch, is succeeded by cherts and black shales on the north side and truncated by a fault on the south side, which brings the black shales in contact with the diabase. The other exposure is met with on the south slope of the Larg Hill, where it forms a small isolated boss, which protrudes through the turf, but of which the relations to the surrounding rocks are concealed. On the crag on the north-west slope of Larg Hill, however, several small arches show the radiolarian cherts in the cores of the folds, succeeded by black shales which pass upwards into flags, shales, and grits. From the black shales in contact with the Arenig

cherts, the following characteristic assemblage of Glenkiln graptolites was obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Dicranograptus ramosus (Hall.)
,, *minimus* (Lapw.)
,, *formosus* (Hopk.)
Climacograptus bicornis (Hall.)

From the black shales in the centre of the gairy the forms given in the annexed list were collected:

Climacograptus bicornis (Hall.)
Dicellograptus sextans (Hall.)
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Leptograptus flaccidus (Hall.)

Lagbaes.—South-westwards along the strike on the east slope of the valley of the Cree, several folds of the Moffat series make their appearance; one at Cardorkin and another at Lagbaes (four miles north-west from Newton Stewart), both being traceable for some distance. Of these, the one east of Lagbaes (Figs. 94 and 95) is the most important, as it reveals Arenig diabase-lava for a distance of 400 yards and upwards of 30 yards in breadth, associated with bright cream-coloured cherts richly

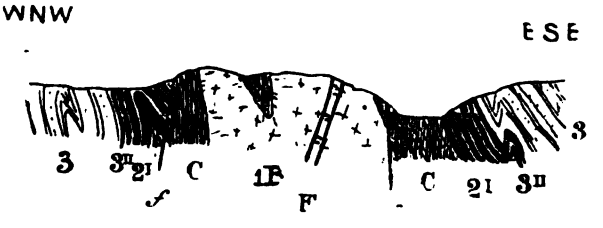


Fig. 95.—Section across Lagbaes Burn, Cardorkin.
(Explanation as in Fig. 94.)

charged with radiolaria. Black shales occur in association with the cherts, though not conspicuously developed. About 200 yards to the east of the lava, where the fold is represented in black shales, the following graptolites were collected: *Didymograptus superstes*, *Dicellograptus sextans*, *Dicranograptus ramosus* var. *spinosus*, *Climacograptus*, &c. Further east, at a point about half a mile south of Loch Middle, another small outcrop of Arenig lava and chert appears with black shales on the south side of the fold. The volcanic rock is highly decomposed, but the chert is seen adhering to the original surface of the lava. These bands of the Moffat series, with the associated volcanic rocks at Cardorkin and Lagbaes, are traversed by intrusive dykes later than the folding of the strata, which are evidently the apophyses of the Loch Doon and Loch Dee granite mass.

Glenhapple Moor.—Excellent sections of the Moffat series are visible on Glenhapple Moor, on the ridge between the Cree and the Bladenoch, about five miles north-west of Newton-Stewart (Sheet 4 of the Survey Map). From Garwachie northwards for a distance of two miles across the moor, a series of compound folds of the black shales trend a few degrees north of east, the whole group being truncated on the north side by a north-east and south-west fault which brings the greywackes of Caradoc age successively in contact with the various subdivisions of the Moffat series. The Arenig volcanic rocks are the lowest beds met with. They rise at two or three places, of which the most important is about a mile and a quarter to the E.N.E. of Garwachie Farmhouse. Here the volcanic rock can be traced for a distance of 400 yards across the moor; it consists of grey pillowy lava, fine-grained and vesicular, resembling the usual diabase type in the Abington area. On the north side it is brought into conjunction with the Caradoc greywackes by the fault already mentioned. Southwards it is succeeded by the radiolarian cherts and by black shales, of which the horizon has not been proved. Not far to the south-west, the lava reappears on another fold, with the cherts and black shales on both sides, while to the south of this arch of lava minor folds of the black shales reveal small exposures of the cherts. At the southmost limit of the black shales, where they come in contact with the greywackes, the following fossils were obtained: *Diplograptus quadrimucronatus*, *Diplograptus foliaceus*, *Leptograptus flaccidus*, *Dicellograptus elegans*, *Dicranograptus Nicholsoni* with the wide angle, *Corynoides calycularis*. It is probable that the highest zone here represented is that of *Diplograptus quadrimucronatus* of the Hartfell division. The sediments in contact with these black shales consist of greywackes and grits with bands of shale. The grits weather with a brown crust, and contain galls and bands of blue and black shales yielding graptolites. This arch is traversed by two dykes of diorite, which granulitise the cherts in contact with them.

Along the strike about 300 yards to the north-east, the lava again appears as a knob in a peaty moor, its relations to the surrounding rocks not being visible. Still further to the north-east, black shales crop out, till, at Glenhapple Farm, on the west bank of the Cree, alternations of greywacke and black shales are visible on a glaciated surface.

South-west from Glenhapple Moor to the ruins of Garwachie Farmhouse, nearly continuous exposures of cherts and black shales rise on successive folds. On a prominent knoll, about 200 yards N.N.W. of the loch at Garwachie, a mass of black shales has yielded a few Hartfell forms, viz.: *Climacograptus caudatus*, *Dicellograptus caduceus*, *Corynoides calycularis*, and *Diplograptus foliaceus*. A short distance to the east of this section, and about the same distance north of the loch, the cherts appear, together with black shales, which contain *Cœnograptus gracilis* and *Lasiograptus bimucronatus*. It is evident that in the Garwachie area

both the Glenkiln and Hartfell groups are represented. Between Garwachie and the river Bladenoch, black shales appear in knolls, where, together with their overlying greywackes, they are altered by intrusive diorite dykes.

Glassoch.—To the north of the Garwachie band, another parallel outcrop of the Moffat series, about half a mile distant, can be traced at intervals for about two miles. About a mile to the north-east of the river Bladenoch the broadest outcrop is visible. Here the cherts appear, and the black shales and greywackes seem to fold round them. At one point next the greywackes the black shales were found to contain *Climacograptus caudatus*, *Diplograptus foliaceus*, *Diplograptus quadrimucronatus*, *Dicellograptus elegans*, *D. Forchhammeri*, *Leptograptus flaccidus*. and *Corynoides calycularis*. At another place, not far to the north-east, flaggy black shales are crowded with *Diplograptus foliaceus*. Probably both the *D. quadrimucronatus* and the *Climacograptus caudatus* zones are here represented.

Glassoch to Carseriggan.—In the bed of the river Bladenoch, and to the south-west of that stream on Carseriggan Moor, several exposures of black shales may be observed with greywackes and shales between. The cherts have not been noticed in the folds. From an outcrop in the Bladenoch River, *Diplograptus foliaceus* and *Corynoides calycularis* were obtained, and from another in the field at a bend of the road, about a quarter of a mile west of Ford House, *Climacograptus caudatus*, *Diplograptus foliaceus*, *Dicellograptus elegans*, and *Corynoides calycularis* were collected. About half a mile to the north of Carseriggan Farmhouse, where there are several outcrops of black shales, they appear at the edge of a peaty hollow, where they have furnished *Diplograptus foliaceus*, *Corynoides calycularis*, and *Climacograptus*. In a quarry at the roadside (south side), 500 yards E.N.E. of the Black Burn, cherts and black shales occur. From a portion of these shales the following species of graptolites were collected: *Climacograptus caudatus*, *Lasiograptus margaritatus*, *Dicellograptus elegans*, *Cryptograptus tricornis*, and *Corynoides calycularis*.

Black Burn, Drumabrennan.—Still further to the south-west, at a bend in the Black Burn east of the footbridge, and north of Drumabrennan Farmhouse, black shales rise in the midst of greywackes, the beds dipping to the south-east. On the south bank the greywackes rest on the black shales at the foot of a small escarpment, but a little to the south-west the two groups are brought together by means of a fault. In the bed of the stream, strips of greywacke alternate with black shales, probably as the result of folding. In the centre of the burn, close to the greywackes, a dark, coarse, sandy shale was found to contain *Diplograptus quadrimucronatus*, *D. foliaceus*, *Cryptograptus tricornis*, *Retiolites (Neurograptus) fibratus*, *Dicranograptus ramosus*, *Dicellograptus* sp., *Corynoides calycularis*, and *Acrotreta Nicholsoni*. A few yards further down stream, in the bed of the burn on both sides of the ford, flaggy black shales with flinty bands have

furnished specimens of *Climacograptus caudatus*, *C. bicornis*, *Dicranograptus ramosus*, and *Corynoides calycularis*. From the ford down to the second band, a distance of 100 yards or so, the section shows an alternation of greywackes and black shales. For 500 yards to the south-west of the first section described north of Drumabrennan, the black shales are visible at intervals in the burn and by the roadside as far as Drumabrennan School. Thereafter for upwards of a mile to the south-west the evidence is obscured by peat and drift; the black shales, however, reappear at the roadside west of Balminnoch Lodge. On the hill slope south-east of Loch Heron and the Black Loch, much-shattered black shales occur in the midst of greywackes, and have supplied only fragments of *Dicellograptus* and *Diplograptus*.

Ringdoon, Tarf Water.—On a hill named the Tulmerrick Hill, and chiefly on the north-west slope, mid-way between Ringdoon and Mark Broom Farmhouses, numerous exposures of black shale are to be seen which display the radiolarian cherts at two localities. From a cliff towards the western limit of the hill, close to a small burn, in a large mass of black shale, the following fossils were collected: *Diplograptus foliaceus*, *Climacograptus*, *Dicranograptus ramosus*, and *Corynoides calycularis*. Towards the northern limit of these exposures, alternations of dark sandy shales and greywackes make their appearance.

Carsecreagh Fell.—To the S.S.W. of Ringdoon, a great development of the Moffat series measures upwards of a quarter of a mile in breadth. At a spot 650 yards south of Drumpail Bridge, at the head of a dry gully, a small exposure of pillowy lava appears in the middle of cherts and mudstones, followed by black shales. The north-west slope of the hill is composed chiefly of cherts and black shales, and the north hill-top of cherts and mudstones. These mudstones, like the cherts, contain radiolaria, which project from the freshly fractured surfaces. These folded members of the Moffat series are evidently truncated by a fault which runs in a north-east and south-west direction at an oblique angle to the axes of the folds of the Moffat Shales, thus giving rise to a feature that now forms a dry hollow. South of this feature greywackes and shales appear without any representative of the Moffat series.

Ben Leight.—The structure described in the foregoing paragraph seems to be prolonged to the south-west into Ben Leight, which rises to the south of Loch Strand. The higher part of this hill is composed of black shales, cherts, and mudstones, repeated by numerous folds, the general dip being to the S.S.E.

Camrie.—In the Camrie Burn (Sheets 3 and 4 of the Survey Map), which traverses the south-western prolongations of the bands of black shales on Ben Leight, and falls into the Luce a mile above Glenluce, the relations of the strata are clearly shown. At a point in this stream where it flows north and south, about half a mile N.N.W. of White Cairn Farmhouse,

there are frequent repetitions of the cherts and black shales, the cherts appearing on six separate folds within a distance of 120 yards. On the west bank of the stream two fossiliferous localities were found in the black shales. One of these yielded the following forms: *Pleurograptus linearis*, *Leptograptus flaccidus*, *Diplograptus foliaceus*, and *Corynoides calycularis*. The other locality, about four feet to the south, supplied specimens of *Leptograptus flaccidus*, *Diplograptus foliaceus*, *D. quadrimucronatus*, *Dicellograptus caduceus*, *Dicellograptus Morrisi*, *D. elegans*, and *Climacograptus caudatus*. This is the only place to the south-west of the river Ken from which *Pleurograptus linearis* has been recorded. The cherts underlying the Moffat Shales and the succeeding greywackes occur on the east bank of the river.

Though the zonal Glenkiln graptolites were not obtained in this part of the Camrie Burn, there can be little doubt that they occur in these folds. For along the strike of the southmost outcrop of chert, about 200 yards to the south-west, the black shales on the north limb of the anticline, within two inches of the cherts, yielded *Dicranograptus minimus*. A little further from the cherts, the black shales were found to enclose Hartfell forms, including *Climacograptus caudatus*, large form of *Diplograptus foliaceus*, *Corynoides calycularis*, and *Dicellograptus*.

About 600 yards north of Honey Pig (Sheet 4 of the Survey Map), the Camrie Quarry exposes cherts and black shales with *Diplograptus foliaceus*, *Climacograptus caudatus*, and *Corynoides calycularis*. To the north-east, near the parish boundary, a constant reduplication may be traced across the strike of the Moffat series, including the cherts and black shales. These folds merge northwards into the axial fold of Gabsnout, Garviland, and Drumpail. Towards the south-west they can be traced over Camrie Fell towards the Water of Luce, where an extraordinary reduplication of cherts and black shales may be followed for a distance of half a mile across the strike. Some of the rocks here associated with the cherts resemble fine volcanic ashes or tuffs. All the beds, however, are so much cleaved that it is difficult to prove the horizon of the zones by means of graptolites.

A mile to the south-east of Camrie, the radiolarian cherts and black shales appear at Glenhoul, in knolls in the fields and at the roadside. They are traceable for a distance of about half a mile from Blackhill to a point not far north of Glenhoul. No fossils were obtained from these black shales, but they are believed to represent the Glenkiln-Hartfell group. The strata immediately in contact with them are grits.

Gabsnout, Garviland, and Drumpail.—In the Water of Luce, at a point two miles above Glenluce and a little below the mouth of Gabsnout Burn, likewise in the latter stream opposite Gabsnout Cottage, black shales have furnished specimens of graptolites characteristic of the *Dicranograptus Clingani* zone. Again, in the Gabsnout Burn, about 250 yards above the Glenluce road, from black shales in contact with greywackes the following assemblage of graptolites was obtained:

Leptograptus flaccidus (Hall.)
Lasiograptus margaritatus (Lapw.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus caudatus (Lapw.)
,, *bicornis* (Hall.)

The greywackes are here infolded in the shales, which contain forms characteristic of the *Pleurograptus linearis* zone. From this spot the black shale bands can be traced at intervals up stream for some distance; at one locality they are associated with black greywackes, probably representing part of the Hartfell shales.

At a point about 500 yards up the Gabsnout Burn, cleaved fissile black shales which occur alongside of a stone fence have furnished no graptolites. A gap in the section intervenes, and about 100 yards further up there is an exposure of the lava on the south bank. In the bed of the burn to the north of this outcrop, mudstones and cherts appear, and for about a third of a mile up stream black shales can be traced at intervals on both banks. Near a bend in the watercourse, S.S.E. of Mid Gleniron Farmhouse, the black shales have yielded *Dicranograptus ramosus*, *Diplograptus foliaceus*, and *Corynoides calycularis*. Immediately to the east of this bend, prominent knobs of coarse-grained dolerite make their appearance. This rock is not seen here in contact with other sediments, but is followed northwards by debris of chert and black shales. A little higher up, however (where Sheets 3 and 4 of the Survey Map join), it occurs in the midst of cherts and black shales in the form of knobs on the moor. A specimen of this rock (No. 7166), taken from a knob about half a mile W.S.W. of Garviland, shows under the microscope "phenocrysts of altered plagioclase in a matrix of lath-shaped plagioclase and ophitic augite, more or less replaced by chlorite and leucoxene."

Eastwards by Garviland to Drumpail Burn alterations of greywacke and black shales appear in knolls, and in the stream section, about 400 yards W.N.W. of Drumpail, three exposures of black shales separated by greywackes may be seen within 100 yards. The southmost band yields *Cryptograptus tricornis*, *Diplograptus foliaceus*, and *Climacograptus;* the middle band gives *Diplograptus quadrimucronatus*, *Diplograptus foliaceus*, *Leptograptus flaccidus*, *L. capillaris;* and the northmost band contains *Diplograptus foliaceus*, *Dicellograptus moffatensis*, *Leptograptus flaccidus*, and *Glossograptus Hincksi*. Black shales appear along this line of outcrop for a distance of half a mile.

Glen Plantation (Water of Luce, Sheet 3 of Survey Map).—On the west side of the valley of the Luce Water, two miles above Glenluce, and in the line of strike of the band in Gabsnout Burn, the black shales appear in the stream that flows through the Glen Plantation, where the Lower Hartfell Shales are seen in contact with the overlying greywackes, and can be followed for some distance in a south-west direction. On the Challoch Hill, about a mile east of Dunragit, knolls in the cultivated ground show debris of black shales, for the most part much

cleaved. About half a mile north-east of West Challoch Farmhouse, the debris yielded *Cryptograptus tricornis* and *Corynoides calycularis*. Again black shales crop out by the side of the road leading to Dunragit, from a point between West Challoch and Ballochjargon Bridge, also in the fields between this road and Challoch Mill. The radiolarian cherts have not been observed on any of these folds; the black shales are cleaved and shattered, and graptolites are difficult to obtain from them, but fragments of *Diplograptus* and *Corynoides* were collected.

ii. Black Shale Bands between Glen Trool and New Luce.

Glen Trool (Kirkcudbright, Sheet 8 of Survey Map.)—In the picturesque valley of the Trool—a tributary of the Minnoch Water—which drains the wild granite tract north-west of Loch Dee, a broad development of the Arenig cherts and Moffat black shales, like the outcrops on Curleywee and Lamachan already referred to, has been largely affected by contact metamorphism produced by the adjacent granite. An interesting feature connected with these outcrops is the marked deflection in the strike as the strata approach the margin of the granite. In the lower portion of the Trool valley the strike is in a north-easterly direction, while to the north of Loch Trool it is deflected to the N.N.E., along a line roughly parallel to the granite boundary. This northerly trend is specially noticeable on the Buchan Hill, about half a mile north of Loch Trool, where the outcrop of the cherts and black shales is about half a mile in breadth. On this hill also the contact alteration superinduced on these sediments is conspicuous, for in certain black shale bands crystals of chiastolite have been developed alongside of graptolites which have not been wholly effaced; the granulitisation of the cherts, which is such a characteristic feature of the zone near the granite on the Kells range, is manifest here also. Even when we recede from the aureole of metamorphism, graptolites are not readily obtained from many of these outcrops in Glen Trool, owing to the movements to which the beds have been subjected. Evidence has been obtained, however, that the radiolarian cherts in the Trool valley are succeeded by black shales, which yield fossils belonging to the Glenkiln division and the lower sub-zones of the Hartfell black shales. The wonderful plications of the members of the Moffat series are strikingly displayed on the finely glaciated rock slopes above the loch to the east of Glen Trool Lodge. There the arches of chert appear as oval or lenticular masses of no great size enveloped in corrugated black shales, thus showing how a group of strata, which at this point cannot much exceed a thickness of 100 feet, may, by reduplication, cover a broad area at the surface.

Pulnabrick Burn.—One of the best sections for fossiliferous localities is to be found in the Pulnabrick Burn, which rises on the southern slopes of the Benan Hill, and after traversing many outcrops of the black shale series flows into Loch

Trool, about a quarter of a mile west of the shooting lodge. About 500 yards up this stream an exposure of black shales has furnished the graptolites given in the annexed list:

Didymograptus superstes (Lapw.)
Cœnograptus pertenuis (Lapw.)
,, *surcularis* (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Dicellograptus sextans (Hall.)
,, *Forchhammeri* (Gein.)
Leptograptus flaccidus (Hall.)
Cryptograptus tricornis (Carr.)
Corynoides sp.

About 100 yards further up, the following still better assemblage of Glenkiln forms was obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus peltifer (Lapw.)
Clathrograptus cuneiformis (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *mucronatus* (Hall.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
,, *Forchhammeri* (Gein.)

A few yards higher, an outcrop of black shales yielded *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Glossograptus Hincksi*, and *Climacograptus bicornis*.

The course of Torr Lane, nearly a mile below Loch Trool, lays bare numerous exposures of black shales, some of which yield graptolites, as, for instance, about three-quarters of a mile to the north-east of Stroan shepherd's house, where at the northern edge of the alluvial flat they have furnished *Dicranograptus ramosus*, *Climacograptus bicornis*, *Dicellograptus* sp., *Diplograptus* sp., and *Corynoides*.

One section to which passing reference may be made displays greywacke in contact with, and apparently interleaved in chert on the hill slope about two-thirds of a mile north-east of Stroan, opposite the road leading to Caldons, and about 250 yards from the Glen Trool road. Here on several well glaciated surfaces, traceable at intervals for 150 yards, the normal radiolarian chert seems to pass upwards into grey greywacke and grit without the intervention of a fault, and at one place on the top of the ridge the two are interbanded. On the north side of the arch the cherts are succeeded by black shales.

In the Minnoch Water near Glencaird and High Minniwick, and also in the river Cree south of Bargrennan Church, the black shales appear on numerous axial folds. At these localities, and also in Glen Trool, the Moffat series passes upwards into sandy shales, greywackes, and grits.

Kirkhoble, Glenruther, Waterside (Sheet 8 of Survey Map).—Between Kirkhoble on the Cree, and Waterside on the river Bladenoch, a more or less continuous series of outcrops of the Moffat series reveals the Arenig cherts and Glenkiln-Hartfell black shales. About a mile east of Glenruther Farmhouse a small exposure of Arenig lava may be seen, and on the moorland, about 300 yards further north, greywackes and

grits are apparently interleaved in the cherts, while green mudstones and greywackes are interposed between the cherts and black shales. Along the trend of this band south-west from Glenruther, several imperfect outcrops of shattered black shales appear on the roadside between Knowe School and Waterside.

Tannylaggie, River Bladenoch.—To the west of Bladenoch, for a distance of 500 yards across the strike, a constant repetition of cherts, black shales, and greywackes comes to the surface. In the southmost large outcrop of black shales, evidence was obtained of the occurrence of the Lower Hartfell black shales 600 yards south of Tannylaggie Farmhouse, and 250 yards east of the sheep-ree marked on the six-inch map. Here, on the moor, among greywackes, a band of platy sandy black shales is charged with the following graptolites: *Climacograptus caudatus*, *C. bicornis*, *Dicellograptus elegans*, *D. caduceus*, *Diplograptus foliaceus*, and *Dicranograptus ramosus*. In the hard flinty bands specimens of *Dicellograptus sextans* occur.

Towards the south, overlying this fold of Hartfell black shales, grey shales with dark strains are followed by rusty greywackes (irregularly jointed) with partings of grey and blue micaceous shales.

Northwards, the radiolarian cherts appear on two folds of the Moffat series near the sheep-ree. From the arch nearest the sheep-ree the following Glenkiln fossils were obtained: *Didymograptus superstes*, *Cœnograptus gracilis*, *Dicellograptus sextans*, *Climacograptus peltifer*, *C. bicornis*, *Dicellograptus patulosus*, *D. Forchhammeri*, *D. moffatensis*, *Leptograptus flaccidus*, *Dicranograptus ramosus*, *Diplograptus foliaceus*, *Lasiograptus bimucronatus*, and *Corynoides calycularis*. This list makes it probable that a portion of the lowest Hartfell black shale may occur here together with the Glenkiln Shales.

From the sheep-ree northwards for a distance of over 300 yards, the radiolarian cherts and associated sediments crop out in numerous exposures. A remarkable feature of these outcrops is the constant association of greywackes with the cherts in such a way as to suggest that the two types of rock are regularly interbedded. This feature is not confined to the Tannylaggie area; it also occurs in sections further to the south-west and to the north-east in Sheet 8, as already described (p. 396). The ground plan in Fig. 96 shows the relations of the rocks visible in knolls near Shepherd's Cairn, 350 yards south-west of Tannylaggie Farmhouse. The greywackes occur three times between successive exposures of the cherts as the section is followed southwards from the black shale outcrop. The northmost exposure of chert, which is only about a foot wide, is flanked on the north by black shales yielding Glenkiln graptolites, while greywackes are visible on the south side. This thin layer of chert has the normal characters of the radiolarian zone, being charged with recognisable radiolaria, and possessing a grey tint with conchoidal fracture. The same features characterise the central band of chert, which is about seven feet wide, and presents the nodular character well developed.

The band of black shale to the north of the northmost band of chert consists of alternations of black shales, black flinty ribs, and shaly greywacke bands or flaggy shales. The latter seem to be regularly intercalated in the black shales. A thin film of black shale (about one inch thick), about sixteen inches from the edge

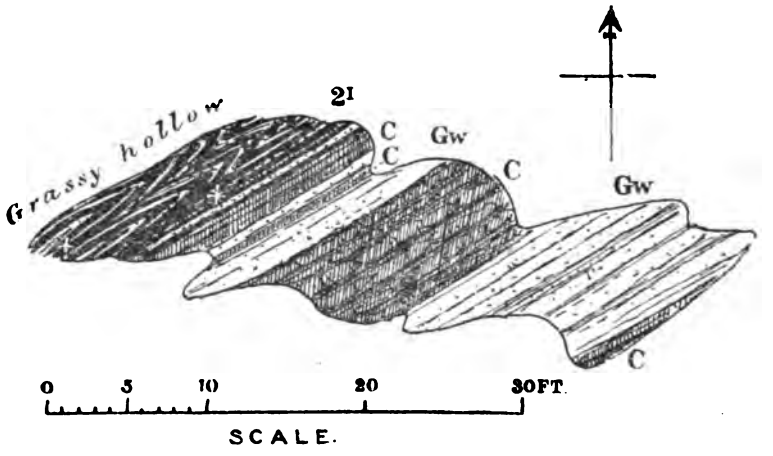


FIG. 96.—Plan of the Glenkiln Strata and Radiolarian Cherts with Interbedded Grits, in Knoll near Shepherd's Cairn, about 350 yards S.W. of Tannylaggie House, Wigtownshire (Sheet 8 of Survey Map).

C. Radiolarian cherts. Gw. Greywacke. 21. Glenkiln Shales.
+ + Localities where Glenkiln graptolites were obtained.

of the chert, yielded in abundance characteristic graptolites of the Glenkiln Shales (*Cœnograptus gracilis*, *Didymograptus superstes*, and *Dicranograptus minimus*). The Hartfell black shales are not visible in this section, the strata being concealed along the line of hollow to the north-west. It is probable that the Glenkiln black shales may here be repeated by folding. North of this hollow greywackes and shales immediately succeed, which are probably of Caradoc age. About 100 yards further north a small fold of black shales appears in the midst of greywackes.

For nearly a mile to the south-west of these exposures at Tannylaggie, the rocks are concealed by drift and peat. On a knoll in the moss, about half a mile E.N.E. of Dirneark, black shales in the midst of greywackes have yielded *Diplograptus foliaceus*, *Climacograptus bicornis*, and *Leptograptus flaccidus*.

Dirneark.—In the knolls at Dirneark Farmhouse (Sheet 4 of the Survey Map), and in the Black Burn, immediately to the east of the house, the relations of the cherts to the black shales are well displayed. Here also it is observable that grits or greywackes are interposed between the cherts and black shales. In the Black Burn, 200 yards E.N.E. of Dirneark Farmhouse, grits occur on both sides of a core of grey cherts, followed by black shales on both sides of the arch. From the black shales on the south limb the following fossils were obtained: *Cœnograptus*

gracilis, *C. pertenuis*, *Dicellograptus sextans*, *Dicellograptus* sp., *Diplograptus foliaceus*, *Cryptograptus tricornis*, and *Climacograptus bicornis*. One of the bands on the north limb of the fold was crowded with *Cœnograptus gracilis*.

It thus appears that in this fold the radiolarian cherts are overlain by greywackes, which are in turn overlain by black shales with zonal Glenkiln forms. It is not improbable that some member of the basal Hartfell black shales may occur in the north limb of the arch, though none of the zonal fossils has been obtained. The beds in the arch are isoclinally folded, the dip being to the S.S.E. at high angles. The black shales belonging to the Glenkiln group exposed in this arch in the Black Burn are flaggy and sandy with dark flinty bands.

Confirmatory evidence of the intercalation of greywackes in the cherts is to be found on a knoll, a few yards to the south of the ruins of Dirneark. There the greywackes are intercalated between the bands of cherts, and a thin layer of greywacke separates the northmost band of chert, about a foot thick, from the overlying black shales. In this instance also the black shales which immediately succeed the greywacke yield zonal Glenkiln forms. Westwards (W.S.W.) from the ruins at a distance of 400 yards, the Moffat series is to be seen in a peaty hollow, exposed in knolls in the midst of the peat and along the margin of the moss. Here also the volcanic rocks occur. In a knoll in the middle of the peat pillowy grey, compact, and vesicular lava is exposed in an outcrop measuring 20 yards in length, bounded on the south side by red mudstones and cherts. The succeeding strata are buried under peat; another knoll, however, 40 yards to the west, exhibits an arch which shows a core of grey cherts, followed southwards by grits and shales, which are in turn overlain by black shales, yielding *Cœnograptus pertenuis*.

To the north-east of the arch of volcanic rocks, the cherts are visible in a drain in the peat moss, while to the south-east of the same arch, at the margin of the moss, a large exposure of much crushed black shales may be seen. Greywackes occur to the north and south of the hollow. It is evident that these exposures form a series of compound folds. This conclusion is confirmed by the occurrence of the cherts and black shales along several lines to the south-west, to the north of Eldrig Loch, where they pass underneath the peat. For about a mile further to the south-west the evidence is concealed, but the Tarff Water has laid bare the black shales, alternating with greywackes and shales, which have furnished specimens of *Cœnograptus gracilis*. Beyond this section in a south-westerly direction the evidence is concealed by drift and peat for some distance, as far as the Cross Water of Luce.

Main Water of Luce.—In the basin of the Water of Luce, important lithological modifications of the Glenkiln-Hartfell Shales are traceable, for both in this stream and in its tributary—the Cross Water of Luce—the black shales containing typical Glenkiln forms are no longer represented by sediments

of the Moffat type, and the basal zones of the Hartfell group are represented by grey shales with black strains or seams and blue-black mudstones.

We shall take first the section in the Main Water of Luce which begins north of Kilfeather Loup, about two miles north of New Luce, and extends for a distance of 130 yards down stream. At the north end little streaks of black shale appear in crushed grey shales, and from one of these bands of blue-black shaly mudstones (two yards broad) the subjoined list of fossils was collected:

Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus tridentatus (Lapw.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
Glossograptus Hincksi (Hopk.)
Corynoides calycularis (Nich.)
Siphonotreta micula (M'Coy.)

These strata occupy the stream for 21 yards, dipping to the N.N.W. in isoclinal folds. On the further side of them an excellent outcrop of black shales covers a space of from 15 to 20 yards of the section and forms a waterfall. Many of the folds in this exposure are normal, but the radiolarian cherts are not visible in the centre of the outcrop. Two thin bands of fireclay are associated with the black shales; the latter are massive and flaggy and quite different in character from the normal Moffat type, with black cherty ribs and partings of sooty shales. The following forms, generally in excellent preservation, and some in great profusion, were obtained from this exposure:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.) in profusion.
,, *pertenuis* (Lapw.)
Lasnograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Dicranograptus minimus (Lapw.)
,, *formosus* (Hopk.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, *Forchhammeri* var. *flexuosus* (Lapw.)
,, *moffatensis* (Carr.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)

Five yards of the section immediately to the south are occupied by greywackes and shales, but further down the Glenkiln Shales reappear much crushed and broken. After a blank in the section for a distance of nine yards, grey sandy shales with black strains appear, and are repeated by folding for a distance of thirty yards. Within this space the Glenkiln Shales are met with at least four times on separate folds. The southmost exposure of these shales yield graptolites in good preservation, the following forms among others having been recorded:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *surcularis* (Hall.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Dicranograptus ramosus (Hall.)

The overlying series of grey shales with black strains occupies the stream section southwards for a distance of a quarter of a

mile, the beds being occasionally associated with greywackes and grits. The black seams yield fragments of graptolites.

Cross Water of Luce.—In this stream, which lies to the east of the Main Water, evidence is obtained of the occurrence of Glenkiln Shales of the type just described, associated with grey shales and black seams yielding fossils of a higher zone. About two miles to the north of New Luce, north of a prominent bend in the Cross Water of Luce, west of Dougaries Farmhouse, greywackes and grits appear in the stream, while at the bend itself dark blue micaceous shales are met with which yield large specimens of *Diplograptus foliaceus*, *Climacograptus bicornis*, *Cryptograptus tricornis*, and *Dicellograptus*. A few yards down stream the following graptolites were got in a thin band of black shales:

Dicellograptus sextans (Hall.)
,, sp.
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall.)

A few yards lower, massive flaggy black shales have supplied the following characteristic Glenkiln assemblage:

Cœnograptus pertenuis (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Lasiograptus bimucronatus (Nich.)
Dicranograptus ramosus (Hall.)
,, *formosus* (Hopk.)
Dicellograptus sextans (Hall.)
,, *Forchhammeri* var. *flexuosus* (Lapw.)
,, *moffatensis* (Carr.)
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)

A blank in the section occurs at this point, but at the old bridge greywackes appear.

From the evidence of this section we may conclude that the grey shales with black strains that enclose graptolites common to both the Glenkiln and Hartfell divisions probably represent the basal portion of the Hartfell group in this region, or at least the passage beds between these two divisions, and further, that to the south of the Kilfeather bands of Glenkiln Shales in the Luce Water, the coarser sediments lying in isoclinal folds between Kilfeather and Gabsnout are mainly if not wholly of Caradoc age.

PORTPATRICK DISTRICT.

Black Shale Bands of Morroch Bay, Colfin, and Garthland.

Morroch Bay.—The clear and well-nigh continuous coast section south of Corsewall Point, in Wigtownshire (Sheet 3 of Survey Map), presents at one locality an admirable development of the Arenig cherts and Glenkiln-Hartfell black shales. These strata are specially displayed in Morroch Bay about a mile and a half south of Portpatrick. In point of clear exposures of the various zones and fine preservation of the zonal forms of grap-

tolites, this is one of the most important sections of the Moffat series in the south-west of Scotland.

The beach of Morroch Bay between the limits of high and low tide, though in places covered with shingle, shows a more or less continuous section of the Moffat series for a distance of a quarter of a mile across the strike. Its breadth at low tide measures from 100 to 150 yards. It thus furnishes special opportunities for following the sub-zones along the strike. A narrow strip of

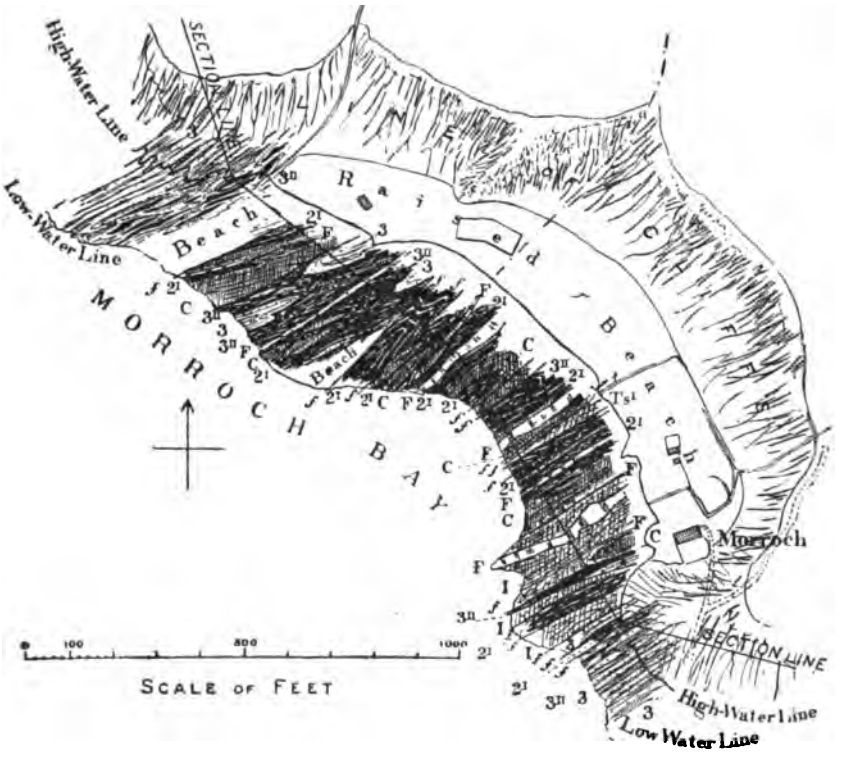


FIG. 97.—Plan of Strata in Morroch Bay, Wigtownshire.

1. Volcanic mudstone and tuff (Arenig). C. Radiolarian chert. 2l. Glenkiln Shales. 3ll. Hartfell Shales. 3. Greywacke, mudstone, and shale (Caradoc). F. Porphyrite dykes. f. Fault. ⌒ Fifty-foot raised beach.

raised beach, from 30 to 90 yards broad, skirts the present beach. Inland the old cliff line rises to a height of 100 or 150 feet, and likewise furnishes a more or less continuous section of the strata.

At the southern headland of the bay, a prominent cliff consists of grey sandy micaceous shales, mudstones like the type of the Barren Mudstones of Moffat, and greywackes with calcareous nodules, the greywackes measuring from one to three feet thick. These strata dip to the S.S.E. at high angles. A fault skirts the base of this cliff, and a thin black shale occurs near it, the horizon of which has not been proved. A few yards from the

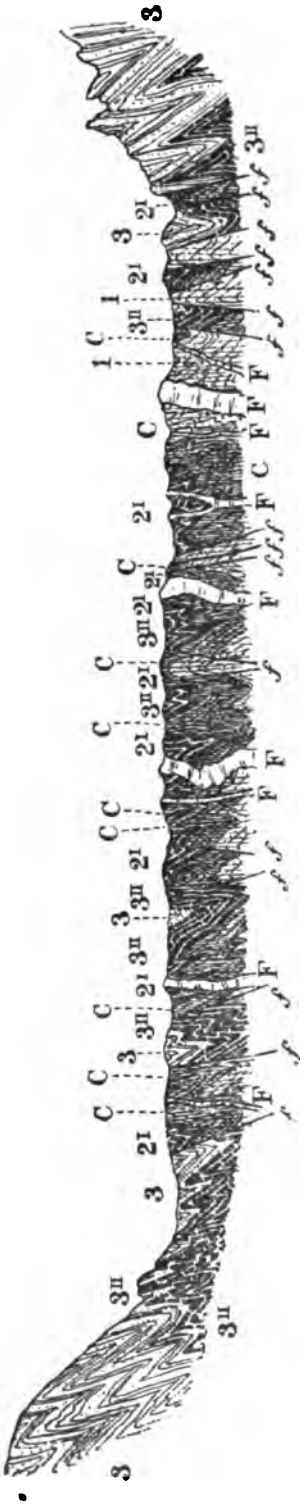


Fig. 98.—Section across the Strata in Morroch Bay. ***(For explanation, see Fig. 97.)***

cliff, and close to a stone fence that skirts the southern termination of the raised beach, a small exposure (about three feet across) of Glenkiln Shales with radiolarian cherts displays black flinty ribs with thin sooty partings or layers of black shales (2^1, Fig. 98), from which the following fossils have been collected:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Cryptograptus tricornis (Carr.)
Climacograptus peltifer (Lapw.)
Diplograptus euglyphus (Lapw.)
Diplograptus foliaceus (Murch)
Dicellograptus moffatensis (Carr.)
,, *sextans* (Hall)
,, *intortus* (Lapw.)

Greywackes occur a few feet to the north (3, Fig. 98), followed by greenish mudstones stained red in places, below high tide mark. Next comes a ridge of black shales (2^1, Fig. 98), highly contorted and bounded on both sides by faults which bring them in contact with green ashy mudstones. This exposure presents the characters of the Moffat type of the Glenkiln Shales, with black flinty ribs from one to four and six inches thick, alternating with genuine black shales. It has yielded the following list of characteristic Glenkiln fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *nitidulus* (Lapw.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Lasiograptus bimucronatus (Nich.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *(Hallograptus) mucronatus* (Hall.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus zic-zac (Lapw.)
,, *formosus* (Hopk.)
,, *ramosus* (Hall.)
,, *rectus* (Hopk.)
Dicellograptus Forchhammeri (Gein.)
,, *patulosus* (Lapw.)
,, *sextans* (Hall.)
,, *intortus* (Lapw.)
,, *elegans* (?) (Carr.)
Leptograptus flaccidus (Hall.)
Glossograptus Hincksi (Hopk.)
Sponge.

North of these black shales a succession of green mudstones occupies the beach for a distance of six yards, when another exposure of black shales is met with, yielding Hartfell forms (3^{II}, Fig. 98). This exposure, which is about 40 yards down the beach from the cottage at the south side of Morroch Bay, gradually thins out seawards, is about six feet broad, and contains outliers of grit. This lenticular patch is apparently truncated by faults on both sides, which bring the black shales in contact with green mudstones. These shales have furnished *Diplograptus quadrimucronatus*, *Leptograptus flaccidus*, and *Diplograptus foliaceus* in abundance, *Dicellograpti* in abundance on one slab, *Corynoides calycularis*, *Climacograptus bicornis*, peculiar variety, and *Dicellograptus Forchhammeri*. This assemblage proves that the shales belong to the Lower Hartfell group, and probably to a high sub-zone of that subdivision of the Moffat series.

Northwards the green mudstones (C, in Fig. 98) may be followed as far as the cottage at the south end of the bay, where they are succeeded by red mudstones. The latter are pierced by an intrusive mass of igneous rock, which sends branching veins into them (Fig 98). Further north they are followed by grey

radiolarian cherts and mudstones, well seen on the beach and dipping E.S.E. at high angles. The hard ribs of radiolarian chert project above the general surface of the interleaved mudstones. These are succeeded in turn by the Glenkiln black shales, and at the junction the cherts alternate with thin black shales, the latter yielding a minute *Climacograptus*. The space occupied by the green and red mudstones and the radiolarian cherts and mudstones from the exposure of Hartfell black shales to the Glenkiln black shales is about 54 yards.

The Glenkiln black shales (2^1, Fig. 98) to the north of the mass of cherts and mudstones have the normal characters of the Moffat type, inasmuch as they consist of alternations of black cherty ribs and black shales, followed by black shales. They have yielded the following assemblage of fossils:

Didymograptus superstes (Lapw.)
Dicranograptus zic-zac (Lapw.)
Thamnograptus scoticus (Lapw.)
Cœnograptus nitidulus (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Diplograptus perexcavatus (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus.
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)

This important development of the Glenkiln Shales, occupying the coast section for 21 yards, is traversed by faults and dykes. It is followed northwards by the green ashy mudstones and cherts, about 14½ yards broad, to the edge of a massive dyke (No. 2), about 12 yards in breadth, which pierces the black shales and mudstones (Fig. 98). The black shales (2^1, Fig. 98) again appear along part of the south side of this dyke. They are separated from the green ashy mudstones by a fault trending south. From the black shales close to dyke No. 2 the following species of fossils have been collected:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *nitidulus* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Diplograptus perexcavatus (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus zic-zac (Lapw.)
Acrothele granulata (Linnr.)

Northwards these black shales extend for a distance of 40 yards, until they are followed by another small exposure of the cherts, bounded on both sides by faults. A few yards to the south of these cherts, a layer in the black shales contains *Corynoides calycularis* in profusion, which may belong to the Lower Hartfell group. About four yards to the north of this small development of the cherts, an exposure of Hartfell black shales displays such an abundance of specimens of *Glossograptus Hincksi* that it has been named the *Glossograptus Hincksi* Band.

Glossograptus Hincksi (Hopk.), abundant.
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.)
,, ,, wide-angled var.
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus tubuliferus (Lapw.)
,, *tricornis* (Hall.)
,, *tridentatus* (Lapw.)
Acrothele granulata (Linnr.)

Another band in this mass of Hartfell black shales yielded:

Glossograptus Hincksi (Hopk.)
Lasiograptus Harknessi (?) (Nich.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
Climacograptus bicornis (Hall.)
Dicranograptus ramosus (Hall.)
Dicellograptus Forchhammeri (Gein.)
,, *flexuosus* (Lapw.)
,, *moffatensis* (Carr.)
,, small variety, in large numbers.

Northwards the black shales are traversed by a third massive dyke, about nine yards across, the distance between dykes No. 2 and No. 3 being about 64 yards (Figs. 97 and 98). To the north of No. 3 the shore is occupied by black shales for a distance of 43 yards, the radiolarian cherts coming to the surface on several small folds. At this point in the coast section the Moffat Shales are truncated by a fault trending to the north. Folded Glenkiln Shales succeed on the north side of this fault, while further north, nearly opposite the point where an ivy-covered wall crosses the raised beach from the old sea cliff, greywackes are infolded in the Hartfell black shales. Here the greywackes lie in narrow synclinal folds, as shown in Fig. 97. From the black shales in contact with the greywackes at this locality (3, 3^{u}, Fig. 98) the following fossils were obtained: *Diplograptus quadrimucronatus*, *D. foliaceus*, *Dicellograptus*, *Leptograptus flaccidus* (in abundance), *Retiolites (Neurograptus) fibratus*, and *Corynoides calycularis*. This layer appears to be on the horizon of the *Diplograptus quadrimucronatus* zone, at the extreme north end of the bay.

Northwards, beyond a fourth prominent intrusive dyke that pierces the Moffat series on the beach (Fig. 98), a series of sharp isoclinal folds repeats the members of the Moffat series and the overlying greywackes. In the midst of these folds small exposures of the cherts show that an ascending series may be traced here from the radiolarian cherts through the Glenkiln-Hartfell Shales to the greywackes.

This belt is abruptly truncated northwards by a fault which brings the greywackes and black shales to the south in contact with the radiolarian cherts to the north. Here, again, a broad development of the radiolarian cherts—upwards of 52 feet across—spreads over the beach, followed by an exposure of Glenkiln black shales, from which the following fossils have been collected:

Thamnograptus scoticus (Lapw.)
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
Dicellograptus sextans (Hall.)
Leptograptus flaccidus (Hall.)

These beds are abruptly truncated by a fault trending to the south. The outcrop of radiolarian cherts and black shales lies to the west of the northmost cottage in the bay.

We have now reached an important part of the section in Morroch Bay, where the Hartfell black shales and the overlying grits (3^{u}, 3, Fig. 98) are repeated by numerous sharp isoclinal

folds that dip southwards. Excellent opportunities are afforded of proving the horizon of the black shale sub-zone in contact with the greywackes. The assemblage of graptolites seems to show that it represents the *Diplograptus quadrimucronatus* zone of the Hartfell black shales. The greywackes and shales which rest to all appearance conformably on the Hartfell black shales must thus represent the Barren Mudstones of the Moffat series, and possibly the very highest sub-zone of the Hartfell black shales. If this inference be correct, then it is apparent that the type of sedimentation is here widely different from that which prevails along the strike of the Moffat region.

Another important feature of the section in the northern part of the bay is the reduplication of the strata by isoclinal folding and the "nosing out" of the synclines of greywacke that overlie the Hartfell black shales. This part of the section thus displays a representation in miniature of the general type of structure which prevails throughout the Silurian Tableland.

At the base of the sea cliff, at the north end of Morroch Bay, where a wall bounds the northern limit of the raised beach near high tide mark, a sharp syncline of grit lies in the Hartfell black shales (3^{u}, Fig. 98). From the band immediately in contact with greywackes the following fossils were obtained:

Diplograptus quadrimucronatus (Hall.)
Dicranograptus ramosus (Hall.)
,, *Nicholsoni* (Hopk.), wide-angled var.
Climacograptus bicornis (Hall.)
Cryptograptus tricornis (Carr.)
Leptograptus flaccidus (Hall.)
Dicellograptus sp.

The following additional forms were obtained from the black shales a little further from the greywackes:

Dicellograptus moffatensis (Carr.)
,, *Forchhammeri* (Gein.)
Diplograptus foliaceus (Murch.)
Leptograptus capillaris (Carr.)
Climacograptus caudatus (Lapw.)
Corynoides calycularis (Nich.)

A striking feature of these shales is the assemblage of forms on the same slab, viz.: *Diplograptus quadrimucronatus*, *Dicranograptus ramosus*, and *Climacograptus bicornis*.

The narrow outlier of greywacke is followed on the south side by several feet of Hartfell shales, which, along the strike seawards, have supplied the fossils given in the accompanying list:

Leptograptus flaccidus (Hall.)
,, ,, pathological var.
Dicellograptus moffatensis (Carr.)
Diplograptus foliaceus (Murch.)
,, *quadrimucronatus* (Hall.)
Diplograptus sp., abundant.
Retiolites fibratus (Lapw.)
Climacograptus bicornis (Hall.)
Corynoides sp.

Below the high tide mark, and rather to the north of the strike of the bands just described, seven lenticular patches of black shales appear among the greywackes, apparently forming isoclinal arches in the overlying sediments. From one or more of

these bands the following forms were obtained: *Leptograptus flaccidus*, *Diplograptus quadrimucronatus*, *D. foliaceus*, *Cryptograptus tricornis*, and *Dicellograptus*.

The sediments which occupy the coast for the next 300 yards in a westward direction consist of greywackes, pebbly grits with partings of shale, and grey mudstones. Near this point on the cliff, at Bellone Cove, two thin bands of black shale which occur among the greywackes have yielded *Diplograptus quadrimucronatus*, *D. foliaceus*, *Leptograptus flaccidus*, *Leptograptus capillaris*, *Dicellograptus Forchhammeri*, and *Climacograptus tubuliferus*.

Colfin Station.—North-eastwards from Morroch Bay, few exposures of black shale are to be found, which may be accounted for by supposing that these strata gradually pass under higher sediments when traced in that direction. The first satisfactory outcrop is seen in a quarry about two miles E.N.E. of Morroch Bay, and 500 yards S.S.E. of Cowend. Here greywackes dipping S.S.E. are accompanied by two feet of black shales, which contain *Diplograptus quadrimucronatus* in excellent preservation, *Leptograptus flaccidus*, *Diplograptus foliaceus*, *Corynoides calycularis*, and *Climacograptus bicornis*. On the south-west slopes of the Bine Hill, from fragments of black shale visible in the fields, *Diplograptus foliaceus* and *Climacograptus* have been collected.

Glenlaggie.—Eastwards across the drift-covered country another exposure is laid bare in Glenlaggie, a ravine cut by a tributary of the Garthland Burn about half a mile south-east of Colfin Farmhouse. About 400 yards up this burn the black platy shales, breaking into small sub-angular fragments, dip S. 10°–15° E. Graptolites are not abundant, but the following forms were here collected:

Diplograptus quadrimucronatus (Hall.)
,, *foliaceus* (Murch.)
Leptograptus flaccidus (Hall.)
Climacograptus sp.
Dicellograptus sp.
Corynoides calycularis (Nich.)

On the north bank of this stream there is evidence of inverted isoclinal folding of the black shales. On the south bank, at the fossiliferous locality, these black shales pass upwards into gritty greywackes.

Colfin Glen.—Rather to the north of the strike of the Morroch Bay band, and about half a mile to the north-west of the outcrop in Glenlaggie, black shales appear in Colfin Glen, between Upper Kilhilt and Colfin Farmhouse. They are seen in the bed of the stream, very much shattered, but yielding traces of graptolites. In the field on the south side of the glen, and not far from the stream, black and dark blue shales occur at the base of the steep slope, dipping south-east underneath greywackes and sandy shales. The dark blue shales contain *Leptograptus flaccidus*, *Diplograptus foliaceus*, and *Dicellograptus*. These strata resemble some of the seams belonging to the horizon of the *D. quadrimucronatus* sub-zone.

Half a mile up the wooded glen, Hartfell Shales again appear, dipping N. 20° W. The shales are platy, and merge into black-blue shales, or dark blue micaceous shales and grits. Some of the bands yield the same assemblage of fossils as noted above, viz.: *Leptograptus flaccidus*, *Diplograptus foliaceus*, *Dicellograptus*, *Diplograptus quadrimucronatus*, and *Cryptograptus tricornis*. Greywackes are found between the arches of black shales in this part of the glen.

Portayew Bay.—About two miles to the south of the important section in Morroch Bay, the Hartfell black shales rise on a fold in the midst of Barren Mudstones in Portayew Bay. About 100 yards to the south of the centre of this bay, where the Portayew Burn flows into the sea, at the base of the rocky cliff, cleaved black shales containing limestone nodules appear; but notwithstanding the cleavage, certain layers contain specimens in good preservation of *Diplograptus foliaceus*, *D. quadrimucronatus*, *Dicellograptus elegans*, *D. caduceus*, *D. Forchhammeri*, *Dicranograptus ramosus*, *Climacograptus*, *Obollela*, &c. These fossiliferous beds plunge underneath grey shales and mudstones, evidently the equivalents of the Barren Mudstones of Moffat, which contain limestone nodules, and are associated with greywacke bands, the whole series forming a prominent cliff. Northwards, contorted and shattered black shales at the base of the cliff have furnished specimens of *Dicellograptus* and *Climacograptus*.

Immediately to the south of the mouth of Portayew Burn a massive dyke of igneous rock extends from the beach up the cliff along the south bank of the burn. Black shales appear on the cliff to the north of this dyke, much crushed, but containing *Didymograptus*, *Dicranograptus ramosus*, *Diplograptus Whitfieldi*, *D. euglyphus*, *Cryptograptus tricornis*, &c.—forms which indicate their Glenkiln horizon. This identification of their stratigraphical position is confirmed by the appearance of the grey radiolarian cherts in association with them while the presence of the Lower Hartfell Shales is indicated by the occurrence of specimens of *Diplograptus quadrimucronatus* in the same outcrop.

Crailloch Burn.—About two miles to the south-west of Stranraer, and to the north of the strike of the Morroch Bay band, several exposures of black shales in the midst of pebbly grits and greywackes have yielded graptolites sparingly owing to cleavage. Of these outcrops, the best is to be found in the Crailloch Burn, about a mile W.N.W. from Piltanton Burn. Greywackes and shales are there laid open, and a few yards south from a stone fence grey mudstones are seen on the west bank of the burn. At the point where this fence crosses the burn, flaky black shales have furnished a few graptolites including *Corynoides calycularis* in abundance in some seams, *Diplograptus foliaceus*, *Dicellograptus*, and *Cryptograptus tricornis*. These beds dip south-east, and beyond the fence black shales appear with a similar south-east dip. At a bend of the stream,

from black shales associated with black flinty ribs of the Glenkiln type the following graptolites have been collected:

Thamnograptus scoticus (Lapw.)
Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicranograptus ramosus (Hall)
Dicellograptus Forchhammeri (Gein.)
Dicellograptus sextans (Hall.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)
,, *cœlatus* var. *antiquus* (Lapw.)

A good exposure of grey radiolarian cherts may be seen on the north bank; westwards, however, greywackes, grits, and shales occur, which must be faulted against the black Glenkiln Shales and cherts. Westwards, near the cottage of Greenknowes, thin seams of black shale are intercalated in greywackes and shales, which, though much cleaved, still show traces of graptolites. Further down the stream, on its south bank at a point due north of Crailloch Farmhouse, and about a third of a mile west of Piltanton Bridge, highly bleached black shales appear from which the black colour has disappeared, the outer surface of the shales being stained red, and the interior of a grey or whitish-grey tint. A few yards up the grassy slope on the south side they yield the following graptolites: *Dicranograptus*, *Dicellograptus*, *Diplograptus foliaceus*, *Climacograptus*, &c. At various places on Crailloch Hill and to the west of Crailloch Farmhouse, black shales and mudstones appear in the midst of greywackes, grits, and shales. They are much cleaved, and only fragments of graptolites have been obtained from them.

Shore-Section from Corsewall Lighthouse to Portpatrick.

The coast from Corsewall Lighthouse southwards for twelve miles to Portpatrick furnishes important evidence regarding the variation in the types of the Llandeilo-Caradoc Rocks from those which prevail in the Moffat series. At various places throughout this section graptolites occur, sometimes in normal black shales and sometimes in thin dark films in grey shales, slates, and greywackes. Owing to the occurrence here of fossils belonging to the Glenkiln and Hartfell divisions, in the dark seams interleaved in coarser sediments, it is extremely difficult to draw a boundary line in this area between the Llandeilo and Caradoc rocks. We will therefore describe the whole series of sediments of Llandeilo-Caradoc age exposed on the coast line southwards from Corsewall Point.

At the northern limit of the section, between Milleur Point, the western headland of Loch Ryan and Corsewall Point—a remarkable development of coarse conglomerate presents itself, the lithological characters of which were described long ago by Mr. Carrick Moore. The rock is well displayed on the sea-cliffs at the lighthouse, where it contains coarse boulder beds, between which, the intervening bands are composed of greywacke and sandy shale. The pebbles lie in a matrix of coarse grit in which

there are abundant small fragments of red radiolarian chert. The largest and most abundant blocks are composed of acid granitoid rocks, which are associated with pebbles of intrusive basic material, similar to the acid and basic intrusive igneous rocks of the Ballantrae volcanic region. Among the smaller blocks are specimens of diabase and diabase-porphyrite lava, serpentine, quartz-felsite, red chert, limestone, and rarely greywackes and black chert.

Southwards for more than a mile from the lighthouse, the strata of massive grits, which have been stained by overlying rocks now removed by denudation, are varied occasionally by more pebbly bands, but without assuming the character of coarse conglomerates. They are vertical or nearly so, and are traversed by many faults which run north-west and south-east. Beyond the Ox Rocks the grits are succeeded by mudstones and hard ribs, the former being green in fresh fracture and strained red in joints. On the shore opposite the Genoch Rocks, conglomeratic bands reappear, with pebbles, two to three inches across, of rocks similar to those in the conglomerate at the lighthouse, the matrix being mainly made up of igneous material. The general dip of the strata is to the S.S.E. at angles varying from 10°-30°. Still further south, the mudstones and hard bands are again met with, rolling about at comparatively low angles, but with a general inclination to the S.S.E., and they continue as far as Portnaughan Bay, where the beds are smashed and reddened along a line of fault. Beyond this fault the beds still dip southwards, but at the southern headland of the bay they begin to dip to the north at angles varying from 5°-17°. From Portnaughan south to Dounan Bay, the same general lithological type continues, consisting of mudstones with hard ribs and sandstone bands.

At Port Long, north of Dounan Bay, the beds are much brecciated, and hematite fills the space between the broken fragments. Again, in the north part of Dounan Bay, they are much shattered and brecciated by faulting. In Port Long—a small cove in this bay—they are traversed by a fault breccia, sometimes fifteen feet broad, which contains hematite. About the middle of Dounan Bay, a powerful fault is seen on the shore, of which the dislocations just referred to are probably off-shoots, and in which occurs a white clay that was mined about 100 years ago, ruins of the old kiln being still visible. This dislocation is probably the south-west continuation of the Glen App fault, which reappears on the west side of Loch Ryan in Lady Bay. North of Dounan Bay, on the west coast, and again on the shore of Loch Ryan near Lady Bay, the strata have been reddened, probably by staining from the younger red rocks now removed. The hematite vein may be due to this cause.

At the south half of Dounan Bay, a marked change takes place in the character of the strata. They now consist of grey and blue sandy micaceous shales with grey limestone nodules, the latter measuring in some instances several feet across. They are

well seen in the bay at low tide. At the south limit of the bay, where the shore road exposes a cliff section of these shales, the dark strains in them have supplied the following forms: *Diplograptus foliaceus*, *Climacograptus bicornis*, *C. Schärenbergi*, *Dicellograptus*, *Dicranograptus ramosus*, *Diplograptus euglyphus*, and a sponge.

Southwards, beyond some grits, flags, and shales, similar shales to those in Dounan Bay appear at a point about 100 yards south of the fossiliferous locality just referred to (Burnfoot on the six-inch map), where they have yielded *Dicellograptus divaricatus*, *Dicellograptus sextans*, *D. patulosus*, *Dicranograptus ramosus*, *Climacograptus bicornis*, *Climacograptus Schärenbergi*, and *Diplograptus foliaceus*. The fossiliferous shales are usually associated with a pebbly band.

From these shales southwards to Saltpan Bay, the shore presents an alternation of greywackes and shales, together with the Dounan shales. At Castle Butt some fossils occur in the Dounan shales. Excellent examples of overfolding are seen at March Port, half a mile north of Saltpan Bay, the beds dipping in isoclinal folds to the south. At a point where a burn discharges into the latter bay, rusty flaggy grey shales with black strains appear as a fold in the grits. The shales contain limestone nodules, and in the dark seams poorly preserved graptolites occur, one being *Climacograptus* like *caudatus*. The fossiliferous shales are here associated with pebbly grits, like a "Haggis Rock," containing fragments of chert, black shale, and lava. In this bay the beds all dip southwards. The grits are succeeded by sandy argillaceous greywackes, till at a spot, named the Swallow Port on the six-inch map, about 200 yards south of Saltpan Bay, two arches of the Dounan Shales show themselves. For a quarter of a mile down the shore, the greywackes alternate with thin bands of shale, till at Slocknamorrow, 300 yards north of Portobello, the Dounan shales reappear and occupy the bay. Here they have yielded *Corynoides calycularis*, *Dicranograptus ramosus*, *Dicellograptus moffatensis*, *Climacograptus bicornis*, and *Climacograptus caudatus*.

North of Portobello the beach exposes another fold of the Dounan shales, and they reappear on several arches south of the port within a distance of a quarter of a mile, where the evidence of inverted folding is very pronounced. For nearly a mile south of March Port, as far as a bay 500 yards south of Juniper Rock (Broad Port), greywackes alternate with pebbly grits and thin shaly partings. At Broad Port, however, the Dounan shales reappear and occupy the whole of the bay. Excellent examples of overfolding occur in this bay, all the overfolds dipping southwards, and there are likewise instances of reversed and normal faults. Limestone nodules are met with, and in the dark strains specimens of *Climacograptus bicornis* and *Corynoides calycularis* were collected.

The south horn of Broad Port Bay is occupied by pebbly grits, and further south the Dounan shales with limestone nodules

reappear. Fine examples of overfolding are also visible, the overfolds still dipping south. The shales occur again in Slouchnawen Bay with numerous limestone nodules, and contain *Dicranograptus ramosus*, *Climacograptus bicornis*, &c.. The same beds reappear about 200 yards south of the mouth of Galdenoch Burn in Wee Port Bay.

Southwards, seams of greywacke about one foot thick with shale partings occupy the coast. Near Saltpans Bay, Dounan shales, much folded, extend along the shore, nearly all the folds being inverted and dipping south. Nodules of limestone and greywacke occur in the shales. The south part of Saltpans Bay is occupied by pebbly grits and greywackes, and for nearly a mile to the south the beds consist chiefly of greywackes with some shale bands.

For half a mile south of the mouth of the burn which falls into Broadsea Bay west of Little Larbrax Farmhouse, the rocks consist of sandy greywackes—intermediate in character between mudstones and greywackes—with a lumpy mode of weathering and thin shale partings. Fine overfolding is visible here in the greywackes. Half a mile south of the mouth of the Larbrax Burn in Broadsea Bay, at the mouth of a small stream W.N.W. of Portslogan Farmhouse, a lenticular band of black shales, charged with typical Glenkiln fossils, occurs along the crest of an arch, in the heart of grey-blue shaly mudstone, followed by grey greywackes on both sides of the isoclinal fold. The beds overlying the black shales are seen to converge up the cliff. The lenticle of black shale is about two feet across at its broadest part. The fossils from it include typical Glenkiln zonal forms, well preserved and readily identifiable. It may be noted that *Cœnograptus* occurs here in great abundance and in excellent preservation. The species here collected are:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *surcularis* (Hall.)
Diplograptus foliaceus (Murch.)
Dicranograptus ramosus (Hall.)
Dicellograptus sextans (Hall.)
Cryptograptus tricornis (Carr.)
Climacograptus Schärenbergi (Lapw.)
,, *bicornis* (Hall.)

From this point southwards along the coast for a distance of 250 yards, the section presents several features of interest. The Arenig cherts appear on two folds, and there are three exposures of fragmental volcanic rocks associated with the sediments. Beyond the inverted arch of Glenkiln shales just described, the mudstones and greywackes appear, the latter occupying the coast line for a distance of about 100 yards. Thereafter for a distance of 40 or 50 yards the beach is strewn with shingle, and here and there isolated skerries appear, composed of blue-grey shales and greywackes. In the centre of these skerries are found the fragmental volcanic rocks.

About 170 yards south of the Glenkiln black shales, a prominent narrow ridge, a few feet in breadth, leaves the cliff and runs out to sea in the form of skerries. The largest development of volcanic rocks is here visible. The core of the ridge is com-

posed of these rocks, which are best seen where the materials are worn by the sea. They consist of agglomerates or tuffs and slaggy lavas. The north side shows about six feet of agglomerate, followed by a thin bed of lava, from eight to ten inches or one foot thick, which is in turn succeeded by ten inches of black shales and greywackes. The lava is much deformed, the vesicles are elongated, and the cleavage-planes which traverse the rock dip south at high angles. The agglomerate, which is not deformed, is charged abundantly with blocks of vesicular lava in rounded or bomb-shaped masses. The most abundant blocks in the agglomerate are grey cherts, next come the black shales, and next in order are greywacke fragments. From one fragment of black shale included in this agglomerate the following list of fossils was obtained:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *sureularis* (Hall.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus sextans (Hall.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)
Climacograptus bicornis (Hall.)
Dicellograptus sp.

Five yards to the north of the ridge just described the tuff reappears on a knob peering through the shingle, while another exposure is met with still further north in the heart of mudstones. The occurrence of fragments of black shale, containing a characteristic assemblage of Glenkiln graptolites, in the tuff associated with sediments that apparently overlie the adjacent Glenkiln shales to the north, may be regarded as indicating the Lower Caradoc age of this volcanic zone. South of the ridge for a distance of 25 yards, grits project in isolated patches through the gravel, till at the south end of the bay grey and black radiolarian cherts appear, with intercalations of green mudstones. The relations to the rocks on the north side are not visible. On the south side of this fold of cherts a thin band of tuff is to be seen in contact with the cherts, succeeded by dark sandy shales or mudstones containing fragments of chert. This series of rocks is truncated by a fault which brings in grits and greywackes that form the headland south of the bay and occupy about 50 yards of the coast section.

The next core reveals another arch of the cherts, truncated on the south side by a fault which brings in grits. On the north side black shales come in contact with the cherts, which are nodular, grey, and streaked black with stained radiolaria. The first foot of black shales yields typical zonal Glenkiln forms:

Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Dicranograptus minimus (Lapw.)
abundant and well preserved.
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
Diplograptus foliaceus (Murch.)

To the north of this band of black shales, and immediately succeeding it, with an inverted southerly dip, dark sandy shales

with black strains, from five to six feet thick, have yielded *Climacograptus bicornis.*

On the south side of the exposure of cherts, the greywackes brought into contact with them by a fault become pebbly, till at a point 100 yards south of the cherts a massive conglomerate comes in at Dove Cove, two-thirds of a mile north of Knock Bay, composed of boulders of greywacke, calcareous nodules, &c., from six inches to two feet across. The calcareous nodules decompose more readily than the matrix, giving the rock a honeycomb appearance. This conglomerate occupies the coast for a distance of 30 or 40 yards.

From this point along the coast, greywackes and shales are seen, till at the mouth of a burn, a quarter of a mile north of Knock Bay, there is an exposure of cherts and black shales, the cherts occurring three times in the midst of the black shales and greywackes. The beds are much shattered and crushed, and fossils are very difficult to obtain from them. After considerable search, only one thin seam yielded graptolites which included *Climacograptus bicornis*, together with *Dicellograptus*, *Corynoides calycularis*, and *Acrotreta Nicholsoni.*

In the skerries at low tide, in the strike of some of the beds just described which occur in the cliff, a series of black and grey grits, with lenticles of black shales, is surrounded with grits. These lenticles have yielded *Corynoides calycularis*, *Diplograptus foliaceus*, and *Climacograptus.* A little to the south, in the same bay, another arch shows thin black shales on the cliff that bounds the beach on the south side of the stream. This is followed by greywackes, and about 100 yards south of this point black sandy shales occur, containing *Corynoides calycularis* in great abundance, *Climacograptus*, and *Dicellograptus.* From Knock Bay to the south of Kilintringan Bay the shore displays a succession of greywackes and shales with black strains yielding graptolites. In Kilintringan Bay the grey and blue shales with dark strains appear in force, the latter yielding *Climacograptus bicornis* and *Cryptograptus tricornis.*

From the foregoing description of the strata exposed on the shore between Corsewall Lighthouse and Kilintringan Bay, north of Portpatrick, it is clear (1) that the radiolarian cherts of Arenig age are exposed on anticlinal folds as far north as Broadsea Bay; (2) that at the same locality the typical Glenkiln graptolites still occur in a normal black shale, followed by sediments which contain thin dark seams yielding graptolites common both to the Glenkiln and Hartfell groups; (3) that between Broadsea Bay and Corsewall Point there is a constant repetition of blue and grey shales with dark fossiliferous seams, sandy greywackes, pebbly grits, mudstones, and shales, which may belong partly to the Glenkiln series (Llandeilo) and partly to the Hartfell (Caradoc). The assemblage of graptolites is such that no very definite opinion can be pronounced as to the relative age of the various sediments.

We will now proceed to adduce evidence that inland, by Cairn

Ryan and Barrhill, to Craiglure Lodge near Loch Doon, the Glenkiln assemblage of graptolites occurs in thin dark films or seams interleaved in shales, slates, and greywackes.

Cairn Ryan District.—This part of Wigtownshire affords proof that the fossils characteristic of the Glenkiln division no longer occur in shales of the central Moffat type. Certain zonal forms confined to the Glenkiln horizon are there found in dark seams interleaved in grey and blue slates and shales. One of the best examples is to be found in the Cairn Ryan Slate Quarries—a locality long known through the discoveries of Carrick Moore. Here grey and blue slates contain thin dark seams yielding *Didymograptus superstes*, *Climacograptus*, *Diplograptus*, and *Dicellograptus*. The fossils are confined to these dark seams, and are not in good preservation. Similar evidence is obtained on the east shore of Loch Ryan, near Polymodie Burn, which joins the sea about a mile and a quarter north of Cairn Ryan. About 20 yards south of the mouth of this burn, the following fossils were collected from dark strains in grey shales intercalated in grits:

Didymograptus superstes (Lapw.)
Lasiograptus bimucronatus (Nich.)
Diplograptus foliaceus (Murch.)
Cryptograptus tricornis (Carr.)
Climacograptus sp.
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Dicranograptus ramosus (Hall.)

Again, about 50 yards north of the mouth of Polymodie Burn, the following assemblage was obtained from similar beds:

Diplograptus foliaceus (Murch.)
,, *euglyphus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Climacograptus celatus var. *antiquus* (Lapw.)
Cryptograptus tricornis (Carr.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
,, like *flexuosus* (Lapw.)

Northwards, the shore of Loch Ryan to the mouth of Glen App displays a constant repetition of grey and blue shales and greywackes, having a general dip to the south-east at high angles (Sheet 7 of the Survey Map). At the roadside at the mouth of Glen App, the graptolites given in the annexed list were collected from dark seams in grey shales or slates:

Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Dicellograptus sextans (Hall.)
,, *divaricatus* (Hall.)
,, *patulosus* (Lapw.)
Lasiograptus bimucronatus (Nich.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Corynoides calycularis (Nich.)

Similar evidence is obtained in the district of Barrhill (south-west corner of Sheet 8), where a great development of grey shales with occasional greywacke bands, though resembling lithologically the Lowther Shales (Caradoc), yet in certain dark sandy seams furnish a characteristic assemblage of Glenkiln graptolites. This shaly group is well exposed in Feoch Burn and

Cross Water, both tributaries of the river Duisk, and also in the Laggish Burn—an affluent of the Pollgowan Burn—the general inclination of the strata being to the south-east at high angles. Excellent fossiliferous localities occur in the Cross Water, which joins the Duisk River from the south-west at the village of Barrhill. In this section, at a point above the Linn Dubh, three-quarters of a mile south-west of Barrhill, and 400 yards S.S.E. of Ward, dark micaceous sandy shales, weathering with a rusty coating on the joints, have furnished the following fossils:

Didymograptus superstes (Lapw.)
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *Whitfieldi* (Hall.)
,, *foliaceus* (Murch.)
Cryptograptus tricornis (Carr.)
Lasiograptus bimucronatus (Hall.)
Dicellograptus moffatensis (Carr.)
,, *divaricatus* (Hall.)
Dicellograptus sextans (Hall.)
,, sp.
,, *patulosus* (Lapw.)
Dicranograptus ramosus (Hall.)
Climacograptus bicornis (Hall.)
,, *cœlatus* var. *antiquus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Leptograptus flaccidus (Hall.)
Siphonotreta micula (M'Coy.)

On the south bank of this stream, opposite the spot where the foregoing list of graptolites was collected, grey mudstones with leaf-like black seams and greywackes occur, the dark seams yielding zonal forms of the Glenkiln division. About 300 yards further up the section, near a small linn, grits and shales with dark strains are exposed, the sequence of beds differing lithologically from those just referred to, which furnish the typical Glenkiln graptolites. Yet the dark seams afforded the following zonal Glenkiln forms:

Cœnograptus gracilis (Hall.)
Lasiograptus bimucronatus (Nich.)
Dicellograptus sextans (Hall.)
Dicranograptus ramosus (Hall.)
Climacograptus bicornis (Hall.)
Diplograptus euglyphus (Lapw.)
,, *perexcavatus* (Lapw.)
Cryptograptus tricornis (Carr.)
Corynoides calycularis (Nich.)

The Cross Water, from the Linn Dubh to the village of Barrhill, flows over a constant repetition of grey shales with black strains and greywackes, the dark seams yielding various zonal Glenkiln forms, including *Cœnograptus gracilis, Lasiograptus bimucronatus, Dicellograptus sextans, Diplograptus euglyphus.* Similar fossiliferous bands were observed in the river Duisk opposite Blair Farmhouse, and in the Feoch Burn, near Laggan Wood, one mile east of Barrhill village, and again near the head of Laggish Burn, north of Chirmorie.

From the evidence now brought forward, it is apparent that in the Barrhill district the Glenkiln division of the Moffat region (Upper Llandeilo) must be represented by grits, greywackes, and shales associated with thin fossiliferous seams yielding Glenkiln graptolites; for though there is undoubtedly much reduplication of the strata, it is obvious that the sections cannot be explained by the repetition of only one thin seam charged with Glenkiln forms. Throughout the Barrhill district the Arenig

cherts have not been met with; they do not appear for three miles to the north-west of that village, where, in the valley of the Muck Water, they are associated with Arenig lavas.

Kirriemore Burn, Minnoch Water (Sheet 8).—In the basin of the Minnoch Water, in the Kirriemore Burn, east of Kirriereoch Loch, black shales and thin dark seams alternate with grey shales and grits, which have been traced south-westwards to the Minnoch and north-eastwards to the Cross Burn, south of Tarfessock Hill. Perhaps the best sections are those in the Kirriemore Burn, where the strata are repeated by folds, and where one or two fossiliferous localities have been recorded. Graptolites are not readily obtained in the more platy black shales with iron pyrites. In the bank of this burn, about a mile east of Kirriereoch Loch, the black shales dip S.S.E. at 78°, and have yielded the following fossils:

Didymograptus superstes (Lapw.)
Lasiograptus bimucronatus (Nich.)
Dicellograptus sextans (Hall.)
,, *flexuosus* (Lapw.)
,, *patulosus* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
,, *perexcavatus* (Lapw.)
Glossograptus Hincksi (Hopk.)
Leptograptus flaccidus (Hall.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
,, *formosus* (Hopk.)
Cryptograptus tricornis (Carr.)
Climacograptus bicornis (Hall.)
,, *peltifer* (Lapw.)
Brachiopod.

Further down the burn, within half a mile of Kirriereoch Loch, where grey shales alternate with black seams embedded in grits, *Cryptograptus tricornis*, *Climacograptus bicornis*, *Diplograptus foliaceus* were collected.

Craiglure Old Lodge (Head of Girvan Water).—When we pass northwards to the area situated between the north-west margin of the Loch Doon granite and the great fault which brings the Lower Old Red Sandstone against the Silurian rocks, we obtain confirmatory evidence of the intercalation of the Glenkiln fauna in coarse sedimentary deposits. Various exposures of blue or grey shales with dark seams interbedded with massive grits and greywackes are met with near Loch Lure, which can be followed westwards for two miles to the river Stinchar. A glance at the Geological Map (Sheet 8) will show the positions of several outcrops of these fossiliferous shales in that region. One of the best fossiliferous localities is in an old slate quarry by the roadside, near the ruins of Craiglure Old Lodge, where dark blue shales, dipping S.S.E. at high angles, have yielded the following assemblage of graptolites:

Didymograptus.
Cœnograptus gracilis (Hall.)
,, *pertenuis* (Lapw.)
,, *nitidulus* (Lapw.)
Dicellograptus moffatensis (Carr.)
,, *divaricatus* (Hall.)
,, *sextans* (Hall.)
,, *patulosus* (Lapw.)
Climacograptus bicornis (Hall.)
Climacograptus tridentatus (Lapw.)
,, *Schärenbergi* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Dicranograptus ramosus (Hall.)
Cryptograptus tricornis (Carr.)
Leptograptus capillaris (Carr.)
Hyalostelia fasciculus (M'Coy.)

Again, on the banks of the river Stinchar, not far to the south of Craiglure new lodge, similar dark blue shales have furnished the graptolites given in the annexed list:

Cœnograptus pertenuis (Lapw.)
Dicellograptus sextans (Hall.)
,, *patulosus* (Lapw.)
Climacograptus bicornis (Hall.)
Diplograptus euglyphus (Lapw.)
Diplograptus foliaceus (Murch.)
,, *mucronatus* (Hall.)
Cryptograptus tricornis (Carr.)
Glossograptus Hincksi (Hopk.)

The strata throughout the area surrounding Loch Lure are isoclinally folded, the general dip of the strata being south-easterly.

Sediments of Caradoc Age overlying the Glenkiln-Hartfell Shales to the North of the Llandovery Area in Wigtownshire and the Western part of Kirkcudbrightshire.

In the region lying to the north of the Llandovery boundary line in the county of Wigtown and the western part of Kirkcudbrightshire, certain sediments may with considerable probability be referred to the Caradoc formation. The evidence adduced in the forgoing pages leads to the conclusion that along the strike of the Curleywee, Glassoch, and Gabsnout band of black shales (pp. 387–395), the *Diplograptus quadrimucronatus* zone (Lower Caradoc) of the Hartfell black shales is represented, and that on the strike of the Tannylaggie and Glen Trool band the *Climacograptus caudatus* sub-zone (Lower Caradoc) has been recorded. It is therefore fair to infer that the coarse sediments which occupy the synclinal folds between these outcrops may be of Caradoc age.

Along the south side of the Morroch Bay, Gabsnout, and Curleywee bands of black shale a prominent zone of shales, with greywackes and occasional pebbly grits, is regarded as the representative of the Barren Mudstones of the Moffat area. The only localities where the Moffat black shales have been noted as appearing in the midst of these grey shales between the Cree and Water of Luce are (1) at Glenhowl, south-east of Camrie, and (2) between Glassoch and the Cree. The rocks immediately in contact with the black shale bands between Gabsnout, Glassoch, and Cardorkin generally consist of greywackes or grits, followed by grey shales. Those which succeed the Tannylaggie black shales on the south side are composed of grey shales with dark strains, succeeded by grey rusty irregularly-jointed greywackes, with partings of grey and blue micaceous shales. A feature in this series is the occurrence of a band of fine conglomerate or pebbly grit, the pebbles in which range from the size of a pea to two or three inches in length, and consist of quartz, black and grey shales, chert, and greywacke. The rock is sparingly fossiliferous, fragments of *Ptilodictya*, *Petraia*, *Heliolites*, and crinoid stems having been obtained from the

exposures near the Snaip and from the head of the burn a mile and a half north of Glassoch. This fossiliferous grit is well seen on the north bank of the river Bladenoch, about half a mile south-west of the Snaip, whence it can be traced north-eastwards to the Cree. South-westwards it has been observed on Eldrig Fell and Balmurrie Fell (north-west corner of Sheet 4).

In the belt of sediments extending from the Tannylaggie black shales to the Drumabrennan outcrop (p. 397)—a distance of 2½ miles—the Moffat Shales come to the surface along an axial fold in a tributary of the Bladenoch about a mile and a half S.S.E. of Snaip. It is probable, therefore, that no great thickness of sediments overlies the Glenkiln-Hartfell Shales in the north-western part of Sheet 4.

As regards the area between the Glen Trool, Tannylaggie, and New Luce black shale bands on the south, and the valleys of Glen App and Glen Muck on the north, it would be obviously unsafe in the present state of our knowledge to indicate the relative age of the coarse sediments associated with the black shales. Owing to the disappearance throughout that region of the zonal Hartfell graptolites and the intimate association of the Glenkiln forms with shales, greywackes, and pebbly grits, it is probable that a large part of these coarse sediments may be of Upper Llandeilo age, and that some portion may be of Caradoc age. To the north of Glen App and Glen Muck, however, the Arenig lavas, radiolarian cherts appear together with blue-black mudstones which are charged with typical Glenkiln graptolites.

CHAPTER XIX.

III.—THE GIRVAN DISTRICT.

ARENIG-LLANDEILO VOLCANIC SERIES OF BALLANTRAE AND ASSOCIATED SEDIMENTS.

In approaching the study of the stratigraphical arrangement of the volcanic rocks of the Ballantrae region, and their relation to volcanic zones occupying similar horizons throughout the Southern Uplands, it is obviously of importance to begin with those sections that reveal a sequence from the Arenig lavas and tuffs with the overlying cherts to those blue-black mudstones which yield an undoubted assemblage of Glenkiln (Upper Llandeilo) graptolites. Several sections of this nature occur on the shore between Glen App and the valley of the Stinchar; some at the margin of the main volcanic area north of the Currarie Glen, and one at Portandea, near Glen App, where the lavas and tuffs form a small inlier among younger sediments.

Area between Glen App and Ballantrae.

Portandea Section (Sheet 7 of the Survey Map).—About two miles round the shore to the north of Glen App, the relations of the strata are clearly displayed at Portandea—a small bay, where the sea laves the base of a cliff from 150 to 300 feet in height. On the north side of this bay a sloping beach, from thirty to forty yards broad, merges upwards into a raised beach that separates a ridge of rock on the seaward side from the main line of sea cliff. The hollow occupied by the raised beach runs northwards for a distance of 350 yards (Fig. 99).

On the north side of the bay and along the eastern limit of the sandy beach, the volcanic rocks appear for a space which from north to south measures about 100 feet. The lowest visible bed rising from the sandy beach is an amygdaloidal diabase-lava of a green tint with small vesicles, and showing the pillowy structure already so often referred to and so conspicuous on the Downan shore, to be described presently. It encloses occasional blocks or patches of red mudstone and chert, and the pillow-shaped masses of lava are surrounded by calcareous matter. This bed of lava, which is about twenty-one feet thick (1 B), is overlain by a band of fine tuff, followed by alternations of coarse and fine agglomerate or breccia (1 Ts.), which contain numerous

small angular fragments of red chert. Higher up the cliff the agglomerate is succeeded by twenty-seven feet of fine-grained slaggy lava resembling the lower bed.

Overlying this volcanic zone, red radiolarian cherts and mudstones (1 and 2 C, Fig. 99) are visible on the cliff and on a prominent stack to the south-east of the volcanic rocks. The upper bed of lava dies out southwards, and the red cherts and mud-

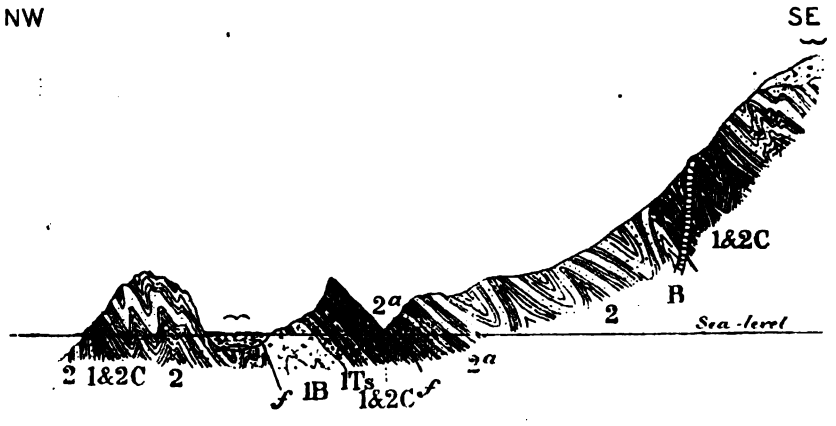


Fig. 99.—Section of Strata at Portandea, South of River Stinchar.

1B. Diabase lava. 1Ts. Agglomerate (Arenig). 1&2C. Radiolarian chert. 2a. Dark shale with Glenkiln graptolites. 2. "Tappin's Group." B. Dolerite dyke (Tertiary). ~ Beach deposits. ~ Boulder clay.

stones, which rest directly on the agglomerates, are succeeded by green mudstones; the united thickness of the red and green beds being upwards of forty feet. They dip to the south-east, and are followed in normal order by green mudstones and greywackes, which include a band of dark or blue-black mudstone that breaks with an irregularly conchoidal fracture (2a). This recognisable bed, exposed about fifty yards to the south-east of the volcanic rocks, is charged with graptolites characteristic of the Glenkiln division as well as with small brachiopods; the former, though stunted in development, are nevertheless well preserved and easily determinable. The fossils given in the annexed list were here obtained:

Dicranograptus zic-zac var. *minimus* (Lapw.)
Cœnograptus pertenuis (Lapw.)
Diplograptus euglyphus (Lapw.)
Climacograptus Schärenbergi (Lapw.)
Dicellograptus sextans (Hall.)
,, *moffatensis* (Carr.)
Dicellograptus patulosus (Lapw.)
Dendrograptus sp.
Lingulella lepis (Salt.)
Acrothele granulata (Linnr.)
Obolella sp.
Discina sp.
Sponge-like body.

The occurrence of fragments of *Dendrograptus* in this assemblage is worthy of note, as this genus rarely appears in the Glenkiln Shales throughout the uplands; still it has been

recorded from that horizon in the Snar Water, near Snar Castle (see p. 321), in the Leadhills area.

The strata in the section at Portandea, from the Arenig volcanic rocks, radiolarian cherts, and mudstones, to the blue-black mudstones with Glenkiln graptolites, form one limb of an arch which is truncated by a fault that runs in a north and south direction along the hollow occupied by the raised beach at the base of the cliff. The rocks that form the seaward ridge west of the raised beach consist of green mudstones and greywackes with a south-east dip.

About 150 yards to the S.S.E. of this section, the red cherts and green mudstones are again brought to the surface by two isoclinal folds. Along the west side of the westmost fold, a north and south fault truncates the green cherts and brings them in contact with the overlying green mudstones and greywackes. From the amount of debris of the dark graptolitic mudstone at the base of the cliff it is clear that this band must occur at several localities on the adjoining slopes.

In a grassy field about 500 yards to the north-east of Portandea, a small quarry hole shows the dark graptolitic mudstone belonging to the same horizon and yielding *Dendrograptus*, *Dicranograptus minimus*, *Dicellograptus sextans*, and *Climacograptus cælatus*.

At a point about 300 yards to the S.S.W. of Portandea, another outcrop of the green cherts and mudstones with radiolaria may be seen near the foot of the March Burn. Higher up the section, near the foot of some cascades, the dark graptolitic mudstone appears. The grey mudstones, shales, and greywackes, which follow the graptolitic mudstones in normal order, have certain peculiar lithological characters, which are recognisable along the south-eastern margin of the Stinchar volcanic area. Indeed, they have been traced from the shore at Portandea north-east to the Tappins Hill, in the valley of the Stinchar, about six miles E.N.E. of Barr. The greywackes have a regular system of jointing, weather with rounded edges, and vary from a few inches to a foot or more in thickness. Though these beds have been carefully searched at various localities they have failed to yield any trace of organic remains. For the sake of convenience, they will be referred to as the "Tappins group" in the description of the rocks on the south side of the Stinchar valley.

On the shore about a quarter of a mile north of Portandea, the red mudstones are arranged at the foot of the cliff, in a series of four isoclinal folds within a distance of fifty yards. One of the folds extends for a distance of 300 yards along the cliff, and passes underneath the sea to the north of Portandea. The cores of the arches are formed of red cherts with radiolaria and mudstones; these are succeeded by green mudstones containing nodules of green and grey chert, sandy calcareous nodules from the size of marbles to blocks a foot and upwards in diameter, and lenticular masses of grit. The nodules of green and grey chert

are crowded with radiolaria. These are followed by green mudstones, dark shales, and greywackes, the general dip of the strata being eastwards. Some of the dark shale bands occupy the position of the graptolite shales in the Portandea section just described.

Northwards, on the shore near Turf Hill, and to the west of Glendrishaig House, the red mudstones and cherts are visible on another isocline, where, on the north side of the outcrop, they come in contact with green sandy greywackes, shales, and mudstones which dip to the south-east at 30°. The shore northwards from Glendrishaig to Brakness Hole presents a constant repetition of green mudstones and greywackes, dipping towards the south-east at angles from 40° to 50°. The strata are cleaved, the planes of cleavage being at a slightly higher angle than those of the bedding.

Glen Currarie, Shallochbraik Burn, and Brakness Hole.—Another inlier of Arenig volcanic rocks and radiolarian cherts is traceable for about a mile and a half from Glen Currarie across Shallochbraik Burn to Brakness Hole, on the shore north of Glendrishaig. Beginning with the section in Glen Currarie at the northern limit of this inlier, we find at the mouth of the glen green mudstones, flags, and sandy greywackes ("Tappins group,") rolling about at gentle angles and rising northwards to 50° and 60°, the beds being well displayed at the side of a road leading to Currarie Farmhouse. Near the mouth of the Shallochbraik Burn, which joins the main stream about 300 yards up the glen, the red mudstones and radiolarian cherts appear on the south bank of the Currarie Burn. For nearly 400 yards along the glen, above this junction, the stream forms the boundary between the red cherts with radiolaria on the south-east bank and the green mudstones and greywackes on the north-west side of the stream, the graptolitic mudstones not being visible at this locality. Where the red cherts cross the glen, 400 yards above the junction of the streams, they are well displayed, the radiolaria occurring in abundance. About fifty yards above this point the red jaspideous cherts rest directly on dark fine-grained lava, followed by the peculiar green "diabase-porphyrite" which is so prominently developed in the volcanic zone of this inlier. It here forms the floor and walls of a rocky gorge, and is succeeded by a bed of volcanic agglomerate visible on the north bank of the stream. This agglomerate is followed by a mass of "diabase-porphyrite" lava which occupies the section for a distance of 100 yards.

In the south-east limb of the fold the red mudstones and cherts, owing to the reduplication, occupy the stream for 250 yards. In the midst of these cherts, the "diabase-porphyrite" appears on a small fold, close to the spot where a grey felsite dyke traverses the section in a W.N.W. direction. The eastmost exposure of the cherts in Glen Currarie lies about 1150 yards up from the coast line. These rocks are then succeeded by green mudstones, flags, and greywackes.

The Shallochbraik Burn likewise furnishes a cross-section of the same isoclinal arch of Arenig volcanic rocks and cherts. On the north limb of the fold, red cherts and mudstones appear at the foot of this burn, and stretch along the channel for a distance of 100 yards. They are much folded where pierced by a dyke of hornblende-felspar rock. Their junction with the Arenig lava is visible at the point where the burn issues from a rocky gorge, the lava being a fine example of the typical "diabase-porphyrite" *(porfido verde antiquo)*, with large green porphyritic felspars in a green fine-grained matrix. For a distance of from 300 to 400 yards the stream flows through the gorge which has been carved out of the bedded lavas. At the upper end of the ravine the cherts and mudstones appear on the south limb of the fold. In the core of the volcanic zone in this section the fine-grained slaggy diabase-lava appears, followed on both sides by the "diabase-porphyrite." On the south limb of the fold, owing to repetition by folding, a continuous section of the red cherts and mudstones is traceable for a distance of 100 yards, and even beyond this main outcrop and within the succeeding green mudstones and greywackes, three arches of the red mudstones and cherts may be selected.

In a south-west direction towards Brakness Hole on the shore, much of the evidence is concealed, as the area is mostly under cultivation and only isolated rock-exposures are visible. The lavas in the core of the arch in Shallochbraik Burn are traceable for 800 yards to the S.S.W., and are flanked on the south-east side by red mudstones and cherts. It is apparent, however, that the volcanic rocks are gradually "nosing out" towards the S.S.W., for the folds in that direction are represented in the overlying red cherts, green mudstones, and greywackes. The rapid isoclinal folding is evidently accompanied by faulting, for on the north side of the inlier south of Currarie Port the green mudstones and greywackes are brought into contact with the lavas. The cherts can be traced more or less continuously through the fields to the shore at Brakness Hole north of Glendrishaig, where a fine exposure displays their characteristic ribbed character and highly contorted bedding. At the edge of the sea cliff that overlooks the northern edge of Brackness Hole, a small core of diabase-porphyrite lava protrudes through the cherts, and is separated by a few yards of red chert from a second core of Arenig lava, which can be traced up the slope for a distance of 100 yards. From the fine cliff-section at the head of Brakness Hole it is apparent that the strata must be arranged in sharp folds, because the red cherts run out seawards in a tongue-shaped form, in the midst of mudstones and greywackes.

In the cove south of Brakness Hole three anticlines of the radiolarian cherts crop out in the midst of the green mudstones, flagstones and greywackes.

It is a disappointing feature of this inlier that the graptolitic mudstone which at Portandea overlies the radiolarian cherts

and mudstones has not here been detected in a similar position, though a careful search for it has been made. The cherts and red mudstones are followed by the barren green mudstones, flags, and greywackes ("Tappins group"). We shall now adduce certain sections at the margin of the main volcanic area north of Currarie, where the volcanic rocks and cherts are succeeded by blue-black mudstones yielding Glenkiln graptolites.

Shore Section between Currarie and Downan Point south of the River Stinchar.—Northwards along the shore from Port Currarie for a distance of half a mile, important evidence may be gathered respecting the relations of the Ballantrae volcanic rocks to sediments of Llandeilo age. Graptolites of Glenkiln type have been obtained at two localities from blue-black mudstones which overlie in one case radiolarian cherts and mudstones, and in the other volcanic agglomerates and lavas.

The promotory on the north side of Port Currarie is formed of green mudstones and sandy greywackes. The separate beds of the latter measure generally about a foot or so in thickness, though in some instances they reach four or five feet. These strata, which weather with the characteristic rounded outlines of the "Tappins group," are repeated by many folds, and occupy the coast line for a distance of 200 yards north of Port Currarie, as far as an outcrop of blue-black fossiliferous mudstones which form a dip slope seawards at an angle of 60°, and fold round an exposure of red mudstones and cherts visible at the base of the cliff. The stratigraphical horizon of this band can only be a few feet above the red mudstones and cherts. The bed is not very accessible, but it furnished the following Glenkiln forms after a short search: *Didymograptus*, *Climacograptus cœlatus*, *Dicellograptus sextans*, *D. divaricatus*, and *Dicranograptus* sp. There can be little doubt that a more prolonged examination would increase this list.

Northwards the green mudstones and greywackes of the "Tappins group" are truncated by a fault, beyond which the red mudstones and cherts succeed. Here the cliff is for the most part inaccessible, but at its base the slaggy lava is exposed on one or more folds. At a point 300 yards north from Currarie Port a well-marked reversed fault slopes northwards at an angle of 30°, and gives origin to a cliff nearly at right angles to the trend of the coast line. On the north side of this dislocation the red cherts, mudstones, and associated lavas, which are there thrown into a series of sharp folds, have been made to over-ride the red mudstones and cherts on the south side of the thrust plane. A short distance to the north another fault at a high angle gives rise to a similar feature, and affects beds belonging to the same horizons. It trends to the north, and is probably reversed. On the north side of this disruption there is a much larger development of the lavas than on the south side.

At a point 600 yards north from Currarie Port, the sequence from the volcanic rocks to the fossiliferous mudstones with

Glenkiln graptolites may be again traced. A small dry water-course here traverses the strata from the top of the Knockgown cliff at a height of 250 feet to the sea level. Its position on the coast is due west of Currarie Farmhouse. The accompanying horizontal section (Fig. 100) shows that between the top of the cliff and the sea-level, the rocks are arranged in a syncline and anticline, the graptolitic mudstones forming the centre of the trough.

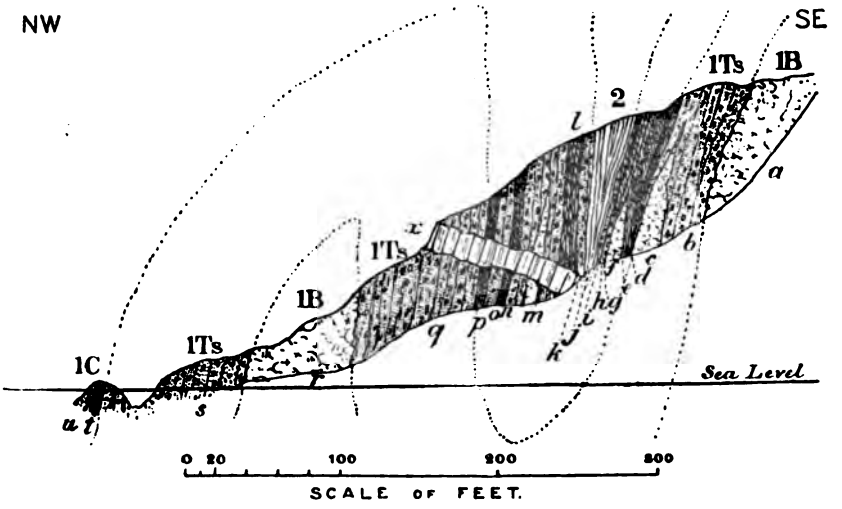


FIG. 100.—Section at Knockgown, North of Currarie, Ballantrae, Ayrshire.

1B. Diabase lava.
1Ts. Agglomerate.
2. Dark shale with Glenkiln graptolites.
a. Porphyritic lava with pillow-structure, 37 ft.
b. Agglomerate with blocks of black chert, 29 ft.
c. Lenticular pillowy porphyritic lava, 17 ft. greatest breadth.
d. Red radiolarian cherts, 5½ ft. above, a few inches below.
e. Red mudstones, 3 ft.

Below.
f. Pillowy lava, 13 ft.
g. Mudstone, 10 in.
h. Ash and calcareous agglomerate, 3½ ft.
i. Fossiliferous mudstones and thin lenticular bed of calcareous agglomerate.

At top of cliff represented by green muds., with a few large scattered blocks of lava and fragments of red and green chert with splendid radiolaria.

j. Fossiliferous mudstones, 5½ ft.
k. Agglomerate (calcareous), 7 ft.
l. Green and grey mudstones, 10 ft.
m. Agglomerate with lenticular bed of lava, 26 ft.
n. Green and red mudstones and cherts, 7 ft.
o. Ash or agglomerate, 9 ft.
p. Green and red mudstone, ashy, 5 ft.
q. Agglomerate, 23 ft.
r. Felstone dyke, pink.
s. Agglomerate.
t. Radiolarian chert.
u. Agglomerate.
x. Felsite dyke.

On the hill slope at the top of the cliff the green porphyritic lava is well shown, and closely resembles the rock of the same type in the Glen Currarie "inlier" already described. Here, too, it forms a conspicuous feature, and has been quarried for dyke-building. The lava from this quarry shows green porphyritic felspars, often measuring more than a quarter of an inch across, in a fine-grained almost black matrix. Under the microscope (No. 5921) "the green colour of the porphyritic felspars is found to be due to chlorite. The ground mass is composed of lath-shaped plagioclase, augite, chlorite, and iron-ores, including pyrite. The structure is sub-ophitic. The original rock was probably a porphyritic dolerite. The rock is a typical diabase-porphyrite according to German nomenclature."

Beginning at the top of the cliff and descending the section, we find a slaggy lava (*a*, in Fig. 100), in which the materials filling the cavities have largely decomposed out, and the vesicular character of the rock is very apparent on weathered surfaces. This slaggy lava, which is about thirty-eight feet thick, is succeeded by about twenty-nine feet of volcanic agglomerate *b*), having a green matrix charged with rounded blocks and masses of slaggy lava together with fragments of black shale, black chert, and rare fragments of red chert. These sedimentary materials have probably been derived from the Arenig black shales and cherts. The average size of the blocks varies from one to three inches, but some measure from a foot and a half to two feet across.

Near the top of this agglomerate a lenticular band of slaggy diabase-lava (*c*) occurs, which measures seventeen feet thick at the bottom of the gully, but thins out before reaching the top of the crag. It is succeeded by a few feet of tuff, and eventually by the red radiolarian cherts and mudstones (*d*), which are 5½ feet thick at the top of the crag, and thin out to a few inches down the slope. These are followed at the top of the scar by a thin layer of volcanic materials and sediments, consisting of mudstones or fine tuff with fragments of red and green chert and occasional blocks of porphyrite, one about three feet across. This band is overlain by green mudstones. The succession at the base of the cliff is somewhat different, for near the point where the felsite dyke crosses the dry watercourse the thin development of cherts is followed by red mudstones (*e*), the two bands measuring about three feet thick, while these are in turn overlain by a lenticular bed of diabase-lava upwards of thirteen feet thick at the broadest part (*f*). Next in order come mudstones (*g*) about ten inches thick; ash and calcareous agglomerate (*h*), 3½ feet; red mudstones, followed by green mudstones yielding fragments of graptolites (*i*). Yet again we find a thin lenticular band of green tuff, which is succeeded by the important zone of fossiliferous mudstones with Glenkiln fossils (2).

The geographical position of this fossiliferous band is well defined, because the mudstones form the roof and walls of a narrow cave which was excavated by the sea when the land stood

Limestone filling spaces between pillow-form masses of lava, on shore near Downan, 1½ miles south of Ballantrae.

at a lower level. The total width of the exposure is about 5½ feet, and as the strata seem to lie in the centre of a syncline the thickness of the mudstones will be about three feet. Weathering spheroidally, and having an irregular fracture, the fossiliferous beds are lithologically quite unlike the Glenkiln Shales of the Moffat region, but they to some extent resemble the graptolitic mudstones that overlie the Stinchar limestone, so minutely described by Professor Lapworth. These dark blue, green, and grey mudstones yield graptolites more frequently in certain layers than in others, which are usually preserved in the solid and often in a perfect state of preservation. Here, again, as at Portandea, the occurrence of *Dendrograptus* is noteworthy in association with many characteristic zonal Glenkiln graptolites, as given in the annexed list:

Dendrograptus gracilis (Hall.)
Didymograptus superstes (Lapw.)
,, *serratulus* ? (Hall.)
,, *extensus* ? (Hall.)
Callograptus Salteri ? (Hall.)
Dicranograptus minimus (Lapw.)
,, *ramosus* (Hall.)
Dicellograptus divaricatus (Hall.)
,, *intortus* (Lapw.)
,, *moffatensis* (Carr.)
,, *patulosus* (Lapw.)
,, *sextans* (Hall.)
,, var. *flexuosus* (Lapw.)
Diplograptus euglyphus (Lapw.)
,, *foliaceus* (Murch.)
Climacograptus bicornis (Hall.)
,, *cælatus* (Lapw.)
,, *Schärenbergi* (Lapw.)
Acrothele sp.
Acrotreta sp.
Lingula sp.
Discina sp.
,, or *Kutorgina* sp.
Siphonotreta micula (M'Coy.)
Discinoid shell.
Sponge.

The westward limb of the syncline presents the following sequence in descending order:—Next the fossiliferous mudstones comes a band of agglomerate (*k*) about seven feet thick, charged with blocks of vesicular diabase-lava, followed by ten feet of green and grey mudstones (*l*), 26 feet of volcanic agglomerate (*m*) with a lenticular bed of lava, seven feet of green and red mudstones and cherts (*n*), nine feet of tuff (*o*), five feet of green and red mudstones (*p*), and 23 feet of volcanic agglomerate (*q*). Here a felsite dyke, about fifteen feet broad, traverses the volcanic rocks, and below its outcrop agglomerate with rounded blocks of diabase-lava is well seen. Westwards, a mass of diabase-lava with pillow-structure forms probably an anticlinal fold, for it is succeeded on the seaward side by volcanic agglomerate similar to that just described, and by an outcrop of red mudstones visible in a little skerry. The dry watercourse which descends the sea-cliff marks a line of fault, probably of no great amount, as the outcrops of the beds are not shifted to any great extent.

From the foregoing descriptive details it is apparent (1) that the blue-black mudstones charged with typical Glenkiln (Upper Llandeilo) organisms rest directly on volcanic rocks; (2) that beneath the mudstones lies an alternating series of tuffs, mudstones, and volcanic agglomerate with lenticular beds of lava, showing that during various pauses in the volcanic eruptions

ordinary sedimentary deposits were laid down; (3) that from the nature of the agglomerates the local centre from which they were discharged may be supposed to have probably stood near the present site of these pyroclastic materials; (4) that as the radiolarian cherts have here only a very limited development, it is reasonable to infer that the prolonged period indicated by the mass of chert elsewhere in the uplands is here represented by the alternating series of volcanic rocks and sediments; (5) that in this portion of the Ballantrae region the evidence points to the continuance of volcanic activity into Lower Llandeilo time.

From this section on Currarie cliff northwards for about two miles to Downan Point, a continuous exposure of volcanic rocks forms the southern termination of the main volcanic area of Ballantrae, and affords the finest sections of the Lower Silurian lavas of the South of Scotland. In the following paragraphs we shall refer to the general characters of the volcanic materials on this part of the coast line and their relations to overlying sediments.

Not far to the north of the section on Currarie cliff, at the foot of a small stream near the Dove Cove, a synclinal fold shows ashy red mudstones with radiolarian cherts, bounded on both sides by volcanic agglomerates resting on diabase-lava. In the Dove Cove there is another infold of agglomerate without the ashy mudstones. About 300 yards further north a deep gully is formed by the weathering out of a grey porphyritic felsite dyke, which traverses the volcanic rocks.

Wilson's Burn.—This small stream, which enters the sea about a mile to the north of Currarie Port, displays for a distance of 700 yards an excellent section of the volcanic rocks, radiolarian cherts, and overlying green mudstones and greywackes (Tappins group).

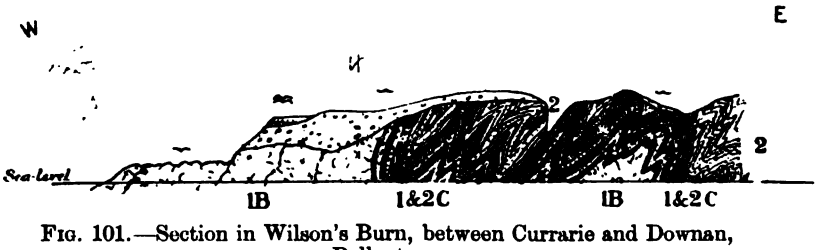
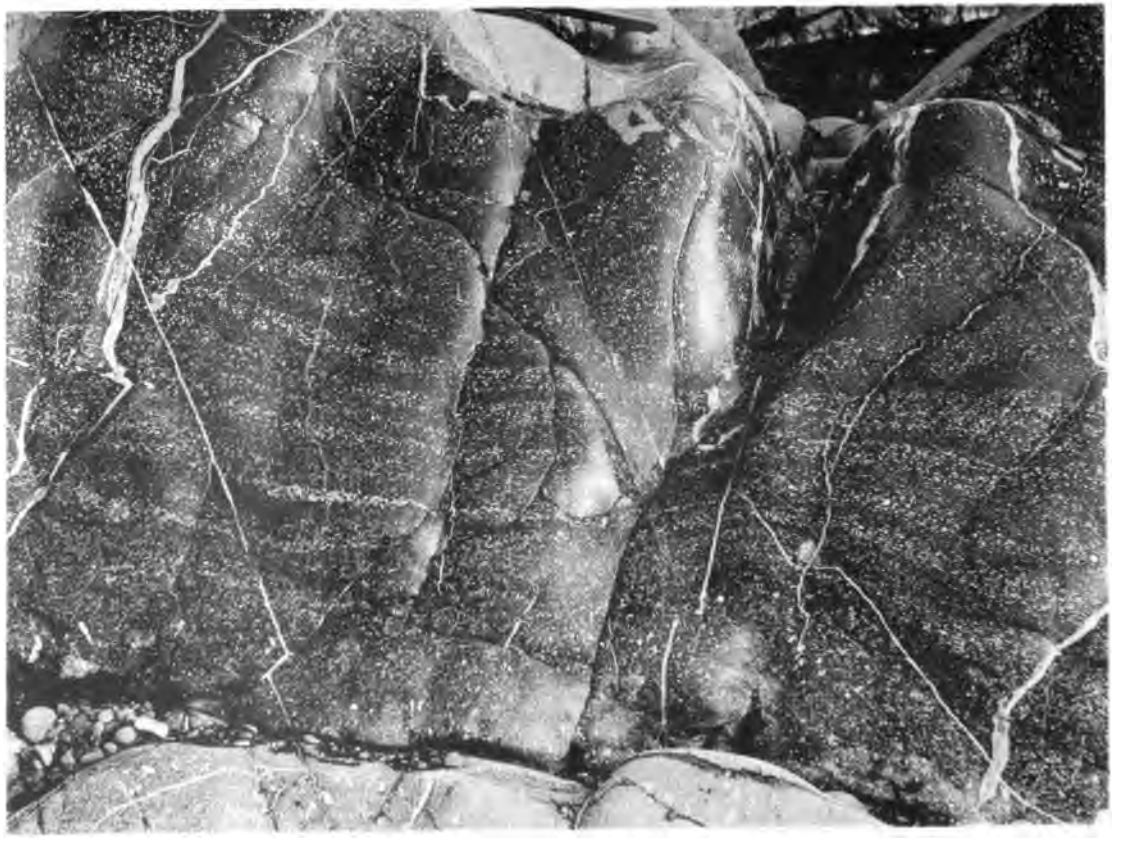


FIG. 101.—Section in Wilson's Burn, between Currarie and Downan, Ballantrae.

1B. Arenig volcanic rocks. 1&2C. Radiolarian chert. 2. "Tappins Group" (Llandeilo). ~ Boulder clay. ≈ 100 Feet Beach. ~ 25 Feet Beach.

In the ascent of the burn from the sea level, the slaggy diabase-lavas are well seen on the cliff, but inland for a short distance they are buried under boulder clay. They are visible, however, in the bed of the stream and on the south bank at a distance of 250 yards from the shore, where they come in contact with the chocolate-coloured mudstones and radiolarian cherts.



Vesicular structure in pillow-form mass of lava, on beach near Downan, one mile south of Ballantrae.

Radiolarian chert filling spaces between pillow-form masses of lava, on shore at Portandea, five miles south-west of Ballantrae.

No agglomerates here occur between the cherts and lavas. These red cherts are immediately succeeded by the green mudstones and greywackes (Tappins group), which extend for a distance of 70 yards, followed by the red mudstones on another anticlinal fold. Eastwards as far as the fork of the stream, a compound synclinal fold extends, composed of green mudstones and greywackes, within which occur two minor folds of the red cherts that underlie the mudstones visible on the north cliff. At the fork, a well-marked anticlinal arch of the red mudstones and cherts is truncated by a fault on the north-west side which brings massive greywacke in contact with the cherts. Above the fork, in the main stream, a broad compound anticline of the red mudstones and cherts is followed by green mudstones and greywackes. Here the strata disappear under a covering of boulder-clay. In this important section the fossiliferous mudstones have not been detected, but their position must be near the base of the green mudstones and greywackes.

Between Dove Cove and Downan Point the coast displays a magnificent section of the bedded lavas, which here present remarkably uniform lithological characters. They are usually fine-grained and non-porphyritic, with numerous small spherical vesicles filled with calcite. A specimen of a fine-grained dark green massive rock taken from the shore below Downan, south of the river Stinchar, shows under the microscope "lath-shaped felspars, pseudomorphs after augite, chlorite, and iron ores. The rock may be termed a diabase, and was originally, in all likelihood, a dolerite."

On the shore near Downan, the remarkable "pillow-structure," so characteristic of the Arenig lavas in the Southern Uplands, is typically displayed (Plates I., II., IV., VI.). The lava-flows are here made up of a series of oval or pillow-shaped masses, varying considerably in size and lying with their long axes parallel to the bedding planes. Each oval mass has a concentric arrangement (Plates I. and V.), the outer zones being vesicular, while the central portion is usually compact, though fragments of other lavas are sometimes observable in the heart of the spheroids. The latter vary in size, some being circular and measuring about six inches across, while the largest measure nine feet in length by two feet in height and one foot ten inches in diameter.

From his recent work on "Ancient Volcanoes of Great Britain," in which Sir Archibald Geikie describes and figures the "pillow-structure," so beautifully shown by the Arenig lavas of Ballantrae, the following extract is taken:

"This singular structure has already been referred to as strikingly displayed in a rock at the top of Cader Idris. It is found in dark basic lavas, probably of Arenig age, which will be afterwards referred to as occurring along the southern flanks of the Scottish Highlands and also in the North of Ireland. It has been observed by Mr. Teall among the rocks of the Lizard, and has been described as occurring in Saxony and California. In these different localities it is associated with jaspers and cherts,

some of which contain abundant Radiolaria. The same structure has been found among the variolitic diabases of Mont Genèvre, and likewise in some modern lavas, as in that of Acicastello, already referred to." *

The spaces between the spheroids of which each lava-sheet is built up are sometimes filled with calcareous matter (limestone), flinty shale, chert, and jasper (Plates II., IV., VI.). The calcareous matter does not seem to have penetrated far down through the successive beds, being confined mainly to the surfaces of the flows. Though no fossils have been found on the part of the coast line south of the Stinchar, yet a little to the north of Bennane Head, north of Ballantrae, flinty shales, probably occupying a similar position in the volcanic series, yielded Arenig graptolites and discinoid shells.

Area between the Valley of the Stinchar and Byne Hill, Girvan.

While on the shore to the south of the river Stinchar, a perfect passage may be traced from the Arenig volcanic rocks and radiolarian cherts to sediments yielding graptolites of Glenkiln (Upper Llandeilo) age; on the other hand, throughout the main volcanic area of Ballantrae, extending from the valley of the Stinchar to the Byne Hill, near Girvan, a strong unconformability separates the Arenig volcanic rocks and radiolarian cherts from the Kirkland conglomerate, Stinchar limestone, and Benan conglomerate, which lie at the base of the richly fossiliferous strata of the Girvan succession. In the following description we shall begin with the Arenig volcanic rocks, radiolarian cherts, and other sediments which are clearly older than the conglomeratic series containing the Stinchar limestone. As already indicated, one of the striking features of the Ballantrae volcanic area is the development of intrusive igneous materials, composed almost wholly of ultra-basic and basic igneous rocks; indeed, the area which these masses now occupy at the surface is nearly as large as that covered by the bedded lavas and tuffs. As the evidence seems to point to the conclusion that the intrusive rocks are probably the last products of volcanic activity in Silurian time in that region, we shall first describe the development of bedded lavas, agglomerates, and tuffs, with the overlying sediments, beginning with the coast sections, where the relations of the volcanic rocks to the radiolarian cherts are most clearly defined.

Bennane Head, Shore-Section.—About two miles north of Ballantrae the shore from the mouth of the Bennane Burn, northwards by Bennane Head to Balcreuchan Port, displays a section of lavas with pyroclastic materials, graptolite shales, and radiolarian cherts which, from a stratigraphical point of view, is by far the most important in the volcanic area of Ballantrae. For here the relation of the cherts to the volcanic

* "Ancient Volcanoes of Britain," vol. i., p. 193.

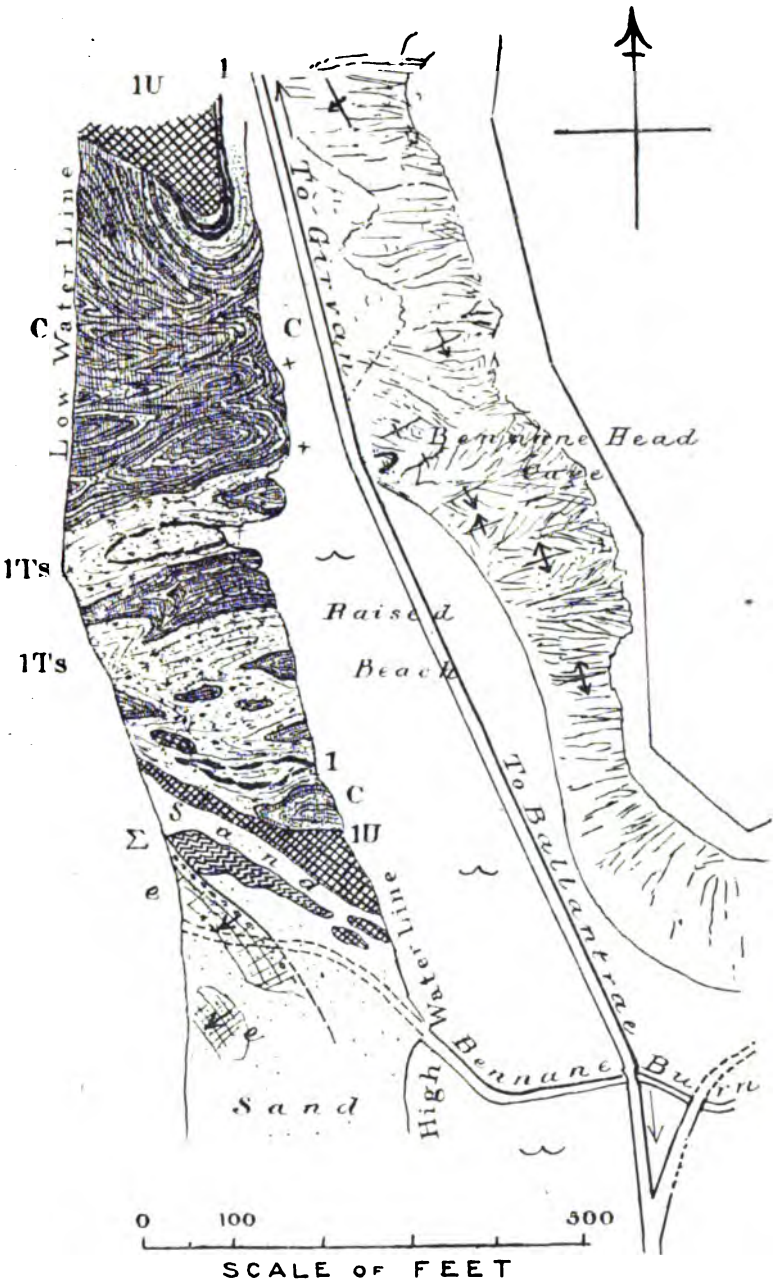


FIG. 102.—Plan of Strata on the Shore, Bennane Head, Ballantrae.

1Ts. Volcanic agglomerate. 1. Arenig black shale. C. Radiolarian chert (Arenig). Σ. Serpentine. 1U. Intrusive basic rock. e. Permian. ~ Raised beach.

FIG. 103. - Section on the Shore, Bennane Head, Ballantrae. (*See Fig. 102 for explanation.*)

series is not only clearly defined, but their age is fixed by the occurrence of a band of graptolite shale which yielded to Professor Lapworth a suite of graptolites of Middle Arenig age. Since this important discovery, other fossiliferous bands have been detected in the course of the revision by the Geological Survey, on other horizons, in the heart of the bedded lavas and tuffs at Balcreuchan Port.

Attention will first be directed to the section on the beach at Bennane Head, where the radiolarian cherts, Middle Arenig graptolite shales, and underlying volcanic rocks are thrown into a series of sharp folds, as shown in the accompanying ground-plan and section (Figs. 102, 103). Thereafter the section on the old sea-cliff east of the road between Girvan and Ballantrae will be referred to. Though the two sections are parallel and traverse beds along the same line of strike, yet, owing to the pitch of the folds, there is a considerable divergence between them.

At the mouth of the Bennane Burn, near high-tide mark, a breccia (*e* in Fig. 102), with fragments of serpentine embedded in a red sandstone matrix, here marks the local base of the Permian (or Triassic) sandstones, which extend along the coast to Ballantrae. This breccia is immediately followed northwards by red serpentine, but the actual unconformability between the two rocks is not here visible. About fifty yards to the north of the mouth of the Bennane Burn, and about 150 yards to the south of the cave in the old sea-cliff, the continuous rock-section begins. Here two small knobs of highly crushed basic rock resembling gabbro are separated by a few yards of sandy beach from an intrusive mass of dolerite (1 U), the intervening hollow being occupied by serpentine (Σ), which is visible on the seaward side at low tide, and is of a bright red colour, much brecciated and veined with calcareous matter. The adjacent mass of dolerite runs apparently E.S.E. and W.N.W., measures about thirty yards across about high-tide level, and decreases in breadth to sixteen yards seawards.

Folds in Radiolarian chert, stack on shore at Benanne Cave, two miles north of Ballantrae.

The radiolarian cherts (C) in contact with the northern edge of the intrusive dolerite, at high-tide mark, form a series of rapid isoclinal folds dipping southwards. From this point northwards for a distance of seventy yards, the shore is occupied mainly by volcanic agglomerate and tuff (1 Ts), in which lie several small outliers of radiolarian chert. This volcanic breccia has a light green matrix, in which are set numerous blocks of vesicular diabase-lava measuring from one to three feet across, together with pieces of red, grey, and black chert. An interesting character of this rock is the abundance of its calcareous matter in the form of veins or lenticles, which have not as yet proved fossiliferous. Another important feature is its inclusion of two outcrops of black shale (1), the more southerly of which lies within a few feet of the northern margin of the intrusive dolerite. Fossils have not been obtained by the Survey from these outcrops.

The northern margin of the volcanic breccia is defined by an outcrop of radiolarian cherts, which, about fifty yards south of the Bennane Cave, form several prominent stacks that show the repetition of the beds by folding and their intercalation with fine tuff and volcanic breccia. Here the cherts, displaying the dark olive-green and grey varieties with abundant radiolaria, form an isoclinal trough dipping southwards at angles from 30° to 40°. The prolongation of this syncline is well seen on the old sea-cliff south of Bennane Cave.

For a distance of about twenty yards north from this outcrop of the radiolarian cherts the rocky beach has been worn down to a comparatively level plane of volcanic agglomerate and tuff underlying the cherts. This volcanic breccia closely resembles that just described. Its important distinction, however, is the occurrence in it of the band of black shale yielding Middle Arenig graptolites, which appears on both limbs of an isoclinal arch. The northmost outcrop, which is traceable for a distance of 31 yards, affords graptolites, whilst the southmost band, which can be followed only at intervals, yields finely-preserved shells in soft black shale. These fossiliferous beds consist of hard black flinty shales with thin partings of soft black shale, which are much disturbed, smashed, and contorted. The following assemblage of fossils was collected from these two outcrops in the course of the revision by the Geological Survey:

Tetragraptus Bigsbyi (Hall.)
,, *bryonoides* (Hall.)
,, *fruticosus* (Hall.)
,, *quadribrachiatus*(Hall.)
,, sp.
Dichograptus multiplex (Nich.)
,, *octobrachiatus* (Hall.)
,, *reticulatus* (Nich.)
,, sp.
Didymograptus extensus (Hall.)
,, *patulosus* (Hall.)
,, sp.
Phyllograptus typus (Hall.)
Dendrograptus sp.
Callograptus diffusus (Hall.)
Climacograptus confertus (Lapw.)
Acrotreta Nicholsoni (Dav.)
Discina sp.
Lingula sp.
Obolella or *Obolus* sp.
Kutorgina or *Obolella* sp.
Discinoid shells.
Sponge rods.

Professor Lapworth recorded the following forms from this band, which are not given in the above list, viz.:—*Didymograptus bifidus* (Hall), *Caryocaris Wrighti* (Salter), and *Dictyonema*. Regarding the assemblage obtained by him from these exposures, Professor Lapworth states that "it is almost unnecessary to point out that we have here a Scottish representative of the well-marked fauna of the middle zones of the Arenig-Quebec or first Ordovician fauna of South Britain, Northern Europe, and Eastern America. Not only is the general facies of the fauna of the well-known Arenig, Point Levis or Skiddaw type, but the Bennane forms occur always in the same association."*

It is significant that though the agglomerate forming the core of the arch between the two outcrops of the Arenig black shales otherwise resembles that overlying the same shales, no fragments of chert or black shales were detected in it. The thickness of the agglomerate that overlies the Arenig black shale and is succeeded by the radiolarian chert varies from eight to twenty feet. The agglomerate is succeeded northwards by a fine exposure of radiolarian cherts and mudstones, which, occupying the shore for a distance of upwards of 100 yards, are repeated by a series of sharp isoclinal folds (Plate VII). Near the southern margin of this belt of cherts thin bands of tuff are intercalated with the chert (Plate VIII.). As this broad outcrop of Arenig cherts and mudstones occupies a compound synclinal fold, the volcanic breccia and Middle Arenig black shales reappear on the north side of the trough. They are there pierced by a mass of intrusive dolerite (1 U), which extends northwards along the coast for 200 yards. At the northern margin of the cherts, the tuff that occurs between them and the intrusive dolerite is fine-grained, and only a few feet thick. Both the black flinty shale and the tuff are welded to the intrusive igneous rock.

At this point on the shore, the strike of the strata changes and now runs nearly due north for over 200 yards. Just above high-water mark the Arenig black shales can be traced at intervals, keeping parallel to the margin of the intrusive dolerite, and bounded on the east by the agglomerates of Bennane Head. Here they have yielded graptolites and linguloid and discinoid shells. Although the Arenig black shales are truncated by the intrusive dolerite, graptolites can be collected from them within a few feet of the junction.

On the old sea-cliff near the Bennane Head Cave, a section east of the main road runs parallel to that on the beach, and exposes mainly the radiolarian cherts. The chief folds that occur on the beach can be recognised on the cliff, which here reaches a height of 250 feet. The absence of the coarse volcanic agglomerate which underlies the cherts is due to the pitch of the folds being inclined towards the sea. Nevertheless, owing to the sharp plications of the strata and to the denudation of the

* "On Ballantrae Rocks of South Scotland and their place in the Upland Sequence." —Geol. Mag., Dec. III., vol. vi., No. 1, p. 20, January 1889.

Alternation of tuff (lighter bands) and Radiolarian chert (darker bands), on shore at Benane Cave, two miles north of Ballantrae.

Folded Radiolarian chert and tuff, cliff south of Bennane Cave, two miles north of Ballantrae.

beds at different levels, the underlying volcanic rocks are exposed in the cores of some of the folds.

About fifty yards to the north of the cave, in the angle of the receding cliff, the Arenig black shales and tuffs appear, with a southerly dip at a high angle. Here the intercalation of pyroclastic material with radiolarian chert is admirably seen in several alternations of these rocks. As each band of tuff contains blocks of the chert, it is evident that, during pauses in the volcanic activity, the radiolarian ooze consolidated on the sea-floor as chert, and was disrupted by the successive explosions. Proceeding southwards, the observer traverses highly folded radiolarian cherts (Plate IX.) till, on reaching the south end of the cliff, he finds the prolongation of the second broad band of agglomerate to the south of the cave. The band of Arenig black shales occurs on both sides of this detrital mass. Its southern outcrop, where the cliff bends to the east, is rapidly folded, and the centre of one of the folds is occupied by chert. From this point eastwards, the volcanic agglomerate forms the higher part of the cliff for about 100 yards, while serpentine is *in situ* at the base, the latter being in all likelihood a continuation of the mass visible on the shore (Figs. 101 and 102). The boundary of the serpentine is shifted by a small fault, which likewise changes the strike of the beds, the trend on the east side of the dislocation being nearly east and west. East of this fault the serpentine forms a small boss, bounded on the north side by radiolarian cherts, on the east by Arenig lava, and on the south by the alluvium of the Bennane Burn. Another knob appears a few yards further east, bounded on both sides by Arenig lava. These isolated exposures of serpentine are believed to be parts of one and the same mass. From the fault eastwards along the cliff to the Bennane Burn—a distance of 100 yards—the radiolarian cherts are continuously laid bare.

Bennane Burn Section.—The first visible rock above the mouth of this stream consists of a band of thin bedded lava, showing typical pillow-structure, and enclosing pieces of chert with radiolaria. It is followed by a thin seam of dark green or black shale, succeeded by dark green and red rediolarian cherts. Here the interstratification of bands of coarse and fine tuff with the radiolarian cherts is well shown at a small waterfall in the main stream, and still more clearly in a small side stream to the west of the line of section. At this latter locality, also, bands of nodular tuff occur between the top of the lavas and the overlying cherts, which are not seen in the main burn.*

A specimen of one of these fine tuffs (No. 5932), composed of a compact hornstone-like rock mottled with green and red tints, taken by the Director-General from a point near the small waterfall in Bennane Burn, shows extremely interesting microscopic characters. Mr. Teall says that it contains "a few minute (·1 mm.) angular fragments of felspar in a somewhat turbid mass,

* This stream section is figured and described by Sir A. Geikie in the "Ancient Volcanoes of Great Britain," vol. i., p. 198.

giving cryptocrystalline polarisation under crossed nicols. When viewed with a high power and a contracted aperture, so as to bring out the slight differences in refractive index of the different constituents, the main mass of this rock shows the structure of a very fine volcanic ash.* Fibrous particles and others showing cusp-like projections between contiguous concavities may be distinctly seen. Both in form and size there is a resemblance between these structures and the glassy particles of the Krakatoa ash which fell on the 'Norham Castle' at a distance of 57 miles from the point of eruption."

Above the waterfall, the Bennane Burn shows a section of red, green, and grey chert with thin partings of mudstone or fine ashy material, for a distance of 50 yards, the whole series being much puckered. These strata are succeeded by green greywackes, composed largely of derivative volcanic material.

Coast-Section from Bennane Head to Balcreuchan Port.—Resuming the shore-section at a point about 150 yards north of Bennane Cave, we find the volcanic agglomerate which underlies the Arenig black shale on the cliff and in the road cutting, the beds being nearly vertical (Plate X.). At a bend in the road, about 300 yards north of Bennane Cave, a good example of a reversed fault with a nearly horizontal plane is followed by a second reversed fault a few feet higher up. On the shore below the road, the vertical bedding of the agglomerate and tuff is well displayed, the parallel bands being etched by the action of the waves, when alternations of fine and coarse material are developed (Plate X.). The included blocks, composed of fine-grained slaggy lava, are, as a rule, more rounded than those in the Knockdolian agglomerate to be referred to presently. The matrix consists of comminuted fragments of volcanic materials, having a purple or green tint.

About 700 yards north of Bennane Cave, beneath the high road where it winds round Port Vad, the junction of the agglomerate with the underlying lava is seen on the cliff at low tide. The thickness of the agglomerate that underlies the Bennane Head black shale, exposed on the shore, between Bennane Cave and Port Vad is 700 feet. Here, at the base of the cliff, by means of a reversed fault the agglomerate is driven over a mass of pillowy, fine-grained diabase, and on the face of the cliff the junction of the lava with the agglomerate is visible. The pyroclastic material on which the lava reposes is a green, highly basic tuff, not unlike that of Mainshill, near Ballantrae, to be described in the sequel. The matrix has a green tint, is fine-grained, decomposes readily, and is abundantly charged with blocks of fine-grained slaggy lava. This tuff, which is about 45 yards in breadth, rests on a second mass of lava, and occupies the whole bay at Port Vad. Here the pillow-structure so characteristic of these lavas is well displayed, both on a stack in the centre of the bay and also on a cliff section that forms the

* See "Untersuchungen über die Lenneporphyre," by O. Mugge: Neues Jahrb.: Beilage Band VIII. (1893), p. 618.

Volcanic agglomerate in vertical beds, Bennane Head, 2½ miles north of Ballantrae.

Ashy mudstone and chert with graptolites, adhering to pillow-form surface of lava, shore near Balcreuchan Port, 3⅛ miles north of Ballantrae.

northern promontory. At this latter point, as in the Downan section above described, the long axes of the pillow-shaped masses are arranged along the bedding planes, which dip seawards at an angle of about 65°.

A specimen of the lava taken from this bay (No. 5922) shows under the microscope that the "rock is too much altered for precise determination. The ground-mass contains acicular microlites of felspar. The amygdules had usually a narrow zone of chlorite on the outside; the interior is sometimes occupied by a granular aggregate of felspar (?). The rock is much veined, and the veins, which traverse both ground-mass and phenocrysts, are apparently composed of felspar and calcite."

From the northern promontory the pillowy lavas are succeeded for a distance of about 100 yards by beautiful porphyritic lavas, with large phenocrysts of felspar (diabase-porphyrite). Their strike being nearly north and south, and their inclination seawards, they are succeeded by agglomerate, which is visible in a gully about 120 yards north from Port Vad, but, owing to the angle of dip, is exposed on the cliff for only a short distance, and then passes out to sea. Northwards for 200 yards the coast-line is formed of fine-grained diabase-lava, succeeded by about ten feet of fine tuff, the bottom bands of which fill up the uneven surface of the underlying lava-flow. The tuffs are followed by diabase-lava, showing pillow-structure, which occupies the shore for a distance of fifteen yards.

We have now reached an interesting point in the section, for here, in a gully running nearly north and south along the strike of the beds, distant about 90 yards from the mouth of a small burn which joins the sea south of Balcreuchan Port, a thin band of fossiliferous red mudstone occurs between beds of pillow lava. From the manner in which this band folds round the rugose surface of the lava and fills up the cracks and cavities below it, we may justly infer that the material must have been deposited between successive volcanic discharges (Plate XI.). The strata here are nearly vertical, and their dip, if they have any, is seawards. The band of red ashy mudstone is extremely hard and splintery, and yields fossils sparingly, but the following assemblage of Middle Arenig fossils was obtained:

Tetragraptus bryonoides (Hall.)
,, *Headi* (Hall.)
Trigonograptus ensiformis (Hall.)
Dichograptus sp.
Climacograptus confertus? (Lapw.)
Caryocaris Wrighti (Salt.)
Siculæ of graptolites.

The underlying lava is highly porphyritic, and the porphyritic crystals on its upper surface project into the red ashy mudstone, suggesting that the underlying mass had not long consolidated before the fine tufaceous mud was laid down.

A few yards to the east of this fossiliferous locality, green, fine-grained, vesicular lava shows typical pillow-structure. Two specimens of it were collected; one from the margin of one of the spheroids, the second from the core of the same "pillow."

The former (No. 6415) under the microscope is found to be composed "of long slender microlites of felspar, giving straight or nearly straight extinction, chlorite, granules of epidote, and possibly also of unaltered augite, a few small specks and plates of iron-ore, and an ill-defined brown substance, which probably represents interstitial matter. The vesicles are filled mainly with calcite, but they sometimes contain also portions of the interstitial matter." The microscopic examination of the specimen from the centre of the pillow-shaped mass (No. 6416) proved that "the rock is not homogeneous. Portions show true igneous structure, being composed of felspar-microlites, chlorite, &c. Other portions are composed of vesicular lapilli, and possess the structure of a tuff."

A few yards west of the mouth of the burn which falls into the sea south of Balcreuchan Port, a zone of chocolate or red ashy sediment is associated with fine tuff. Here, on a cliff formed by these sedimentary beds and fine tuffs, the fossils were obtained from a thin dark ashy seam, which are given in the annexed list:

Tetragraptus bryonoides (Hall.)
,, sp.
Climacograptus sp.
Caryocaris Wrighti (Salt.)
Radiolaria.
Acrotreta sp.
Obolella sagittalis? (Salt.)
Discinoid shells.

This fossiliferous band is shown by these fossils to be of Middle or Lower Arenig age. It is interstratified with diabase-lava and coarse volcanic agglomerate, the latter being visible at the mouth of the burn just referred to. This breccia is followed by lavas showing typical "pillow-structure," which extend as far as the middle of the bay of Balcreuchan Port. Here red mudstones and cherts, lying probably in a synclinal fold, and in all likelihood on the horizon of the Arenig cherts of Bennane Head, are admirably seen on a cliff on the north side of the cove, where they are interstratified with agglomerates. They are also visible in a small promontory in the middle of the bay.

The volcanic origin of the bedded lavas and agglomerates in Balcreuchan Port was clearly recognised by Professor Bonney, whose description is so interesting and accurate that we reproduce it here. "We descended from the high road to the water's edge at Balcreuchan Port, a romantic cove enclosed by precipitous cliffs. On the shore, rather on the southern side, is imperfectly exposed a little of a rather decomposed dark-coloured serpentine, apparently intrusive in a rock consisting of angular fragments of felstone, in an earthy-looking decomposed ground mass. Their condition and the nature of the ground—strewn here with boulders and debris—makes it difficult to form a decided opinion about this rock, but I have little doubt that it is really a coarse porphyrite tuff or volcanic agglomerate. Overlying this is a great mass of hard reddish-coloured rock—here fairly compact—of which the whole cliff appears to be composed. Towards the base, the rock has a rather slaggy aspect, and is slightly vesicular.

It generally exhibits an irregular jointed structure, the most developed planes being rudely parallel to the base; is occasionally slightly columnar, and often rudely spheroidal, this structure being in one part very marked. Sometimes, also, curved sub-spheroidal joints may be seen. The spheroids are often traversed by radial cracks. Where parts of the shells have fallen away, and fragments have been left projecting from the rotten, dusty, or pasty material which has accumulated from decomposition, the rock has a look of breccia. This, however, in the ordinary sense of the word, I am convinced it is not. By clambering along the screes to the south, we found the rock become decidedly porphyritic, the crystals of the plagioclase felspar often being about a third of an inch long. Good specimens of the rock were difficult to obtain, as it was very tough and traversed by minute concealed joints. From the evidence in the field alone, I should not hesitate to consider this a true igneous rock, and probably a lava-flow."*

From Balcreuchan Port north-eastwards to Burnfoot, the coast-line cuts obliquely across the strike of the beds. For a space of 300 yards the section traverses the western limb of the syncline occupied by the red cherts and mudstones, the rocks being composed of lava with pillow-structure dipping towards the south-east. Beyond the centre of the syncline, which is here occupied by agglomerate, fine-grained diabase lavas with pillow-structure extend as far as Games Loup, near Balcreuchan Port. North of that point, the coast-line is defined by a wall of rock formed by hard and brecciated lava; while on the seaward side a hollow runs parallel to this cliff, and beyond the hollow, serpentine is exposed in stacks that rise above the shingle of the beach.

From the foregoing details of the typical Bennane Head section, the following conclusions may be drawn:

(1) The highest visible beds consist of red, green, and grey radiolarian cherts and overlying green greywackes and shales, the cherts being interstratified with tuffs and volcanic breccias. (Thickness of cherts with tuffs, 70 feet.)

(2) Underneath the radiolarian cherts occur coarse agglomerate and tuff, which contain a thin band of black flinty shale charged with Middle Arenig graptolites. (Thickness, 720 feet.)

(3) These agglomerates and tuffs pass downwards into vesicular diabase-lavas and "diabase-porphyrite" lavas, occasionally associated with breccia and tuff, and containing thin fossiliferous seams that yield Middle Arenig graptolites. (Minimum thickness, 700 feet.)

(4) If the correlation of the red mudstones and cherts in Balcreuchan Port with those at Bennane Head be correct, then it is clear that the volcanic series in this shore section must form a synclinal fold.

(5) The nature of the pyroclastic materials at Bennane Head suggests the probability of a local centre of eruption having been situated near that locality.

* Quart. Jour. Geol. Soc., vol. xxxiv., p. 780.

Pinbain Shore-Section.—Another important shore-section occurs at Pinbain, about a mile north of Lendalfoot, where the lavas and tuffs are associated with fossiliferous strata of Arenig age (Fig. 104 ground plan, Fig. 105 section). About

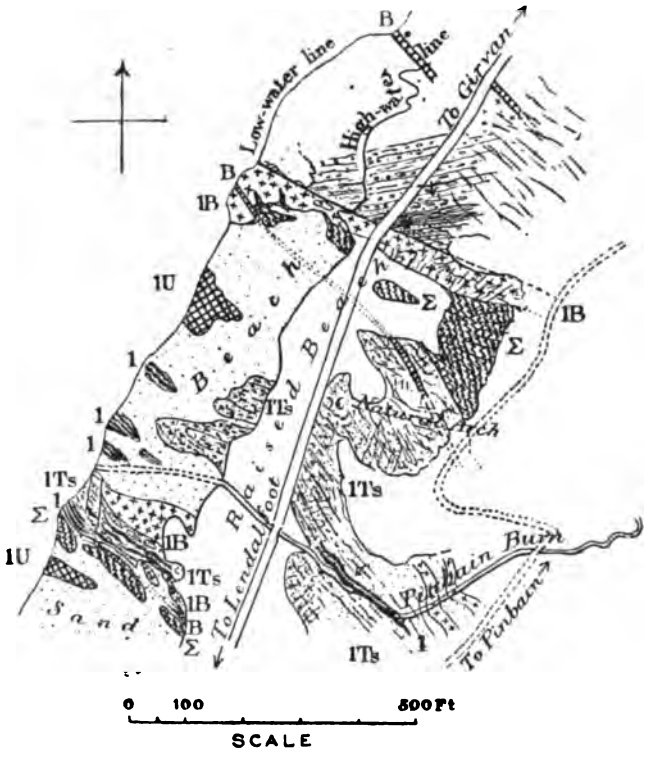


FIG. 104.—Plan of Strata on the Shore, Pinbain, one mile north of Lendalfoot, Ayrshire.

1. Arenig black shale. 1B. Diabase lava. 1Ts. Agglomerate. Σ. Serpentine. 1U. Intrusive basic rock (Silurian). B B. Dolerite dykes (Tertiary). f. Fault.

fifty yards south of the point where the Pinbain Burn enters the sea, the junction between serpentine and black shales is visible, the two rocks being separated by a thin dyke of basic rock about 2½ feet broad. The microscopic examination of this rock (No. 6431) shows that "the dark part appears to be composed of minute augites and altered felspars, but owing to the fineness of the grain and to subsequent alteration it is difficult to be certain. The yellowish-green colour appears to be due to the development of granular epidote. The original rock was probably a basalt." The hardened black shales have here yielded a specimen of *Climacograptus confertus* in fair preservation. Immediately to the north of these shales on the

sandy beach, black, green, and grey shales, interstratified with agglomerate, occupy the coast for a distance of ten yards. The black shale is shattery and breaks into thin flakes. The agglomerate contains blocks of diabase-lava, fragments of black shale, and oval masses of limestone, measuring in one case 4ft. by 3ft. Lenticular masses of lava likewise occur in this banded series of sediments and volcanic breccias.

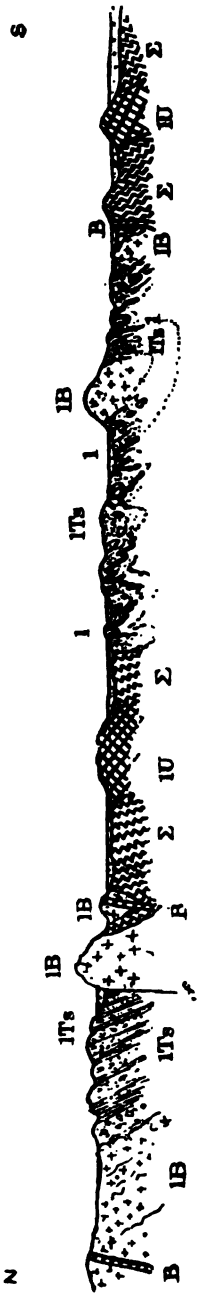


Fig. 105.—Section of Strata on Shore, Pinbain, one mile north of Lendalfoot. *(See Fig. 104 for explanation.)*

Immediately to the north, lavas appear which show pillow-structure, but in places are much brecciated, though on the beach the outlines of the pillows are still preserved (1 B). On the south and west sides the brecciated lava is separated from the sedimentary series by a layer of agglomerate from two to seven feet thick, containing blocks of porphyrite and small fragments of black shale. On the west or seaward side, the black shales are traversed by two small faults (see ground-plan, Fig. 104). The mass of lava, which occupies the coast for a space of twenty yards, forms stacks rising above the sea level near high-water mark.

Not far to the north of the mouth of Pinbain Burn, the volcanic agglomerate again appears, containing blocks of diabase-lava, black shale from six inches to a foot across, black chert, and limestone (1 Ts). West of the mouth of Pinbain Burn, and to the west of this mass of agglomerate, small knobs of black shale are visible on the beach near low-tide level, while another exposure occurs about twenty yards further north, which is covered during high water. A second mass of agglomerate crops out near high-water mark, almost due east of the last skerry of black shales.

The various outcrops of black shale just referred to near the mouth of Pinbain Burn, from the occurrence of *Climacograptus confertus* in one of their seams, are correlated with the Middle Arenig black shales of Bennane Head. Further, it is probable that the masses of agglomerate north of the mouth of Pinbain Burn may be younger than

these sediments, as they contain pieces of black shale and black chert.

About 31 yards north of the northmost exposure of black shales gabbro (1 U) is visible on the sandy beach, and a few yards further north serpentine (Σ) is found in contact with green porphyritic lavas (1 B, see ground plan, Fig. 104).

Returning now to the Pinbain Burn, and ascending this stream from the high road, we find black shales—evidently the prolongations of those visible on the beach—dipping towards the south-east at high angles, and containing oval masses of limestone. Here they occur in the midst of agglomerate, and are succeeded northwards by alternations of tuff and diabase-lava, till the rocks disappear under a deep covering of boulder clay.

To the north of the Pinbain Burn a fragment of the 25-feet beach (Fig. 104) is bounded east of the road by a prominent cliff, and forms two recesses with a projecting spur in the centre. Agglomerate is exposed on the old sea-cliff as far as the more northerly recess, where the narrow band of serpentine visible on the shore forms the central part of the back-ground, bounded on the south side by agglomerate and on the north by green porphyritic diabase-lava. Two stacks project out of this raised beach, one composed of serpentine and the other of volcanic agglomerate. The latter is traversed by a basalt dyke (B) which runs up the north face of the pinnacle.

At the point where the northern margin of the old sea-cliff abuts on the road, dark blue and grey ashy shales, flags, and fine tuffs dip to the S.S.E. at high angles. On the south side they are faulted against the green porphyritic diabase-lava just referred to, and on the north side they are succeeded by volcanic agglomerate, containing bombs of volcanic rocks of various types; one variety consisting of a pink fine-grained felsitic rock, apparently more acid than any of the common diabase-lavas. In the centre of this sedimentary and volcanic series, where the beds consist of hard ashy ribs from two to three inches thick, alternating with shaly mudstones, graptolites have been found in thin blue shales which are remarkably fresh and have not been much disturbed. The following fossils were here collected:

Tetragraptus Bigsbyi (Hall.)
,, *quadribrachiatus* (Hall.)
,, *bryonoides* (Hall.)
Phyllograptus typus (Hall.)
Dendrograptus sp.
Dichograptus sp.
Climacograptus sp.
Caryocaris Wrighti (Salt.)
Discinoid shell.

This assemblage closely resembles that obtained from the Middle Arenig black shales at Bennane Head, though the bands containing them are believed to occupy a slightly lower stratigraphical position.

Proceeding now to the description of the shore-section northwards from the last-mentioned fossiliferous locality to Kennedy's Pass, which marks the northern limit of the volcanic series on the coast, about a mile south-west of Ardwell Bay, we find that

Volcanic agglomerate, Stockenray Bay, 1¼ miles north of Lendalfoot.

the coarse agglomerate beneath the fossiliferous shales is followed by brown fine-grained tuff and sedimentary bands, not unlike those yielding the graptolites at the roadside. Northwards, a band of coarse tuff, like that in Stockinray Bay, to be described presently, is associated with lenticular bands of lava, the beds dipping seawards at high angles. To the north of this tuff, the shore is occupied by a beautiful porphyritic lava ("diabase-porphyrite") with large porphyritic felspars, measuring in some instances 9-10ths of an inch in length. The rock can be traced from the shore up the western slope of Pinbain Hill and over the crest of that eminence, where it varies somewhat in character, becoming in places rather fine-grained and not so markedly porphyritic. On the shore, at low tide, however, it displays the pillow-structure so characteristic of the more fine-grained diabase-lavas. Below high water mark it is pierced by a dyke of basic rock, which separates it from a remarkable type of agglomerate which will now be described.

In Stockinray Bay, about 600 yards north of the mouth of Pinbain Burn, at low tide level, a conglomerate rock with a greenish matrix contains blocks of various volcanic materials, and differs to some extent from the usual pyroclastic materials connected with the lavas. It may be a small patch of the Benan conglomerate which occurs further north in Kennedy's Pass (*postea* p. 498).* On the landward side of this conglomerate a mass of agglomerate occupies a considerable part of the bay. The matrix contains crystals of plagioclase set in a black, compact ground-mass, with a somewhat resinous lustre. Under the microscope, a specimen (No. 6425) shows that "the matrix is absolutely opaque, except at the extreme edge, where it appears to be of deep brown colour." Mr. Teall describes the rock as a porphyritic tachylite. Rounded blocks of porphyritic lava from six inches to a foot across, appear in the agglomerate (Plate XII.). From its general characters, it is probable that the rock may be due to the explosion of a mass of pyroxenic lava. The rocks in this bay are traversed by dykes of porphyrite and dolerite, the former varying much in width and having a tortuous course.

The remarkable agglomerate of Stockinray Bay is succeeded northwards by a fine development of porphyritic lavas, with large porphyritic felspars, from half an inch to an inch in length (Plate XIII.). They form prominent cliffs, which afford excellent opportunities for studying the lithological characters of the rock. In places the felspar crystals are oriented in the direction of the flow of the lava. A specimen (No. 6419) taken from the shore at this locality is thus described by Mr. Teall:—"Phenocrysts of altered greenish felspar in the form of thin tablets, often measuring half an inch across, occur in a dark fine-grained greenish matrix. The microscopic examination shows that the ground mass of the rock is formed of short laths of

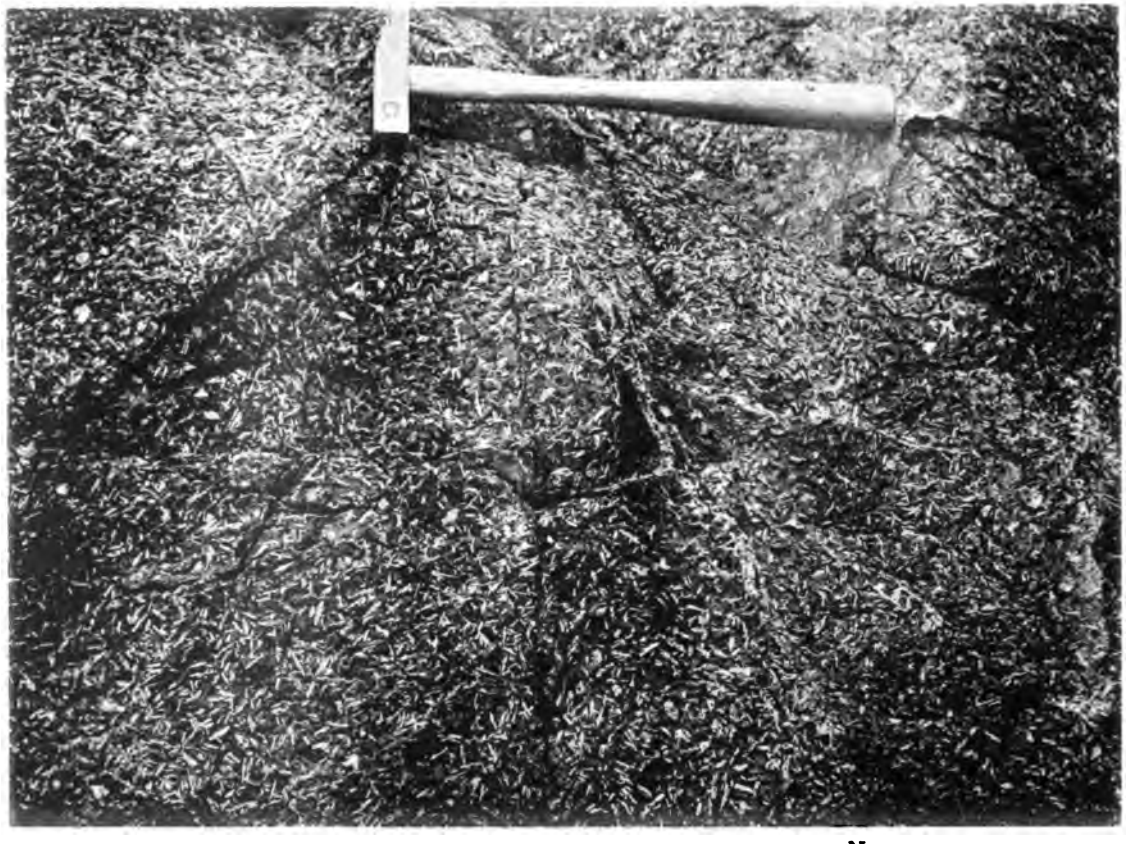
* The Benan conglomerate is associated with the Stinchar limestone (Upper Llandeilo), and must be distinguished from the volcanic agglomerate of Bennane Head of Arenig age.

felspar, chlorite, grains of unaltered augite, and plates of ilmenite. The rock contains also irregular patches of considerable size, entirely filled with aggregates of chlorite. It is a 'diabase-porphyrite,' according to German authors. Felspar concentrates at 2·64 (oligoclase)." These lavas occupy the shore for a distance of about 250 yards, and at their northern limit an irregular layer of jasper and about a foot of green tuff are followed by a mass of basic agglomerate. From this point northwards to the mouth of Kilranny Burn, a distance of 700 yards, the shore displays an alternation of fine-grained vesicular and porphyritic lavas (diabase and diabase-porphyrite), and is traversed by six basalt dykes, some of which give off thin seams or veins.

The fossiliferous strata (Benan Conglomerate, &c.) visible on the beach north of Kilranny Burn that drains the northern slope of Pinbain Hill, will be described in the sequel; at present it may be sufficient to state that, in the bay below Kennedy's Pass, the fault that brings the Benan Conglomerate in contact with the volcanic series is well seen, its course being marked by a small hollow that runs north and south. Here, a basalt dyke about six feet broad rises along the line of fault, and shows a marked linear arrangement of its constituents parallel to its walls. The road section from Kennedy's Pass southwards for 400 yards traverses the Arenig lavas, where they are much shattered and disturbed by the adjacent fault. The thickness of the volcanic series exposed on the shore between Pinbain Burn and Kennedy's Pass is estimated at 1400 feet.

In the foregoing pages we have adduced evidence to prove that in the centre (Bennane Head) and near the northern margin (Pinbain) of the main volcanic area of Ballantrae, volcanic rocks and overlying sediments occur, which, on palæontological grounds, can be shown to occupy similar stratigraphical horizons in the Arenig division of the Silurian system. We shall now proceed to show that near the southern limit of the main area, in the valley of the Stinchar, the Arenig cherts and underlying black shales likewise appear at the surface in association with coarse volcanic agglomerate, as at Bennane Head.

Mains Hill, Ballantrae, and Balnowlart.—Along the valley of the Stinchar, from near the bridge across the river at Ballantrae to Balnowlart, a distance of about a mile and a half, the radiolarian cherts and red mudstones can be traced at intervals in association with tuff and agglomerate. They are exposed at several places on the road, where they are interstratified with fine tuff, and they can be seen on the steep north bank of the river, traversed by dolerite dykes. The best section of them is to be found in a road cutting, at the back of Balnowlart Farm-steading, where the red cherts and mudstones are interbedded with green tuff, and dip to the N.N.E. at an angle of 45°. Certain dark purple seams might here yield fossils; indeed, a fragment of a graptolite was obtained, though it proved to be indeterminable. In the sequel we shall refer



Porphyritic lava, "Diabase porphyrite," Stockenray Bay, 1½ miles N. of Lendalfoot.

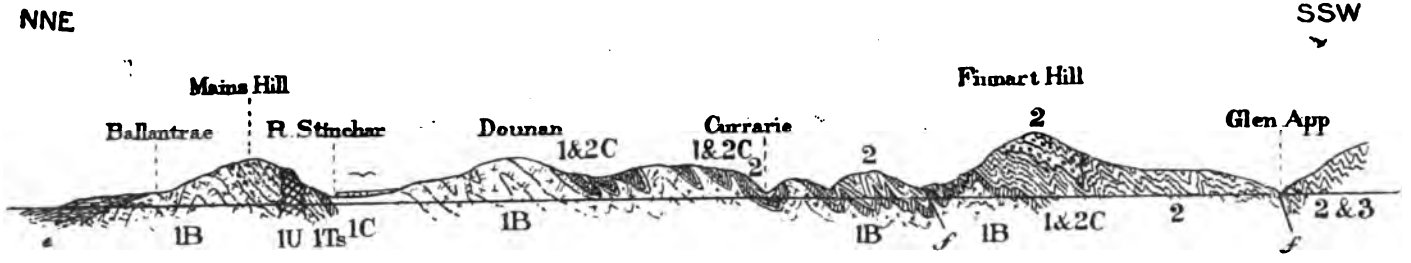


FIG. 106.—Generalised Section from Ballantrae to Glen App, Ayrshire, to show the relation of the Volcanic Rocks to the overlying sediments south of River Stinchar. (Length, six miles.)

1B. Arenig lava. 1Ts. Arenig tuff. 1&2C. Radiolarian chert. 2. "Tappins Group" (Llandeilo). 2l. Glen App conglomerate. 2&3. Llandeilo-Caradoc. 1U. Intrusive basic rock. e. Permian. ff. Faults. ~ Alluvium.

to the occurrence of the radiolarian cherts and black shales on another fold, about a mile further up the Stinchar valley (Fig. 116).

This outcrop of radiolarian cherts is flanked on the north side by a peculiar type of agglomerate, which, extending from Mains Hill near Ballantrae to Balnowlart, with an average breadth of 300 yards, shows in places rude bedding, the planes being inclined at high angles to the N.N.E. It may be best studied in numerous quarries on Mains Hill, within half a mile of Ballantrae. The matrix is green, and contains numerous small lapilli of fine vesicular lava, together with blocks and masses of diabase-lava which contain porphyritic augite and plagioclase. A striking feature of the more basic parts of the mass, and of the enclosed blocks, is the abundance of crystals of augite. In this respect the rock bears a close resemblance to the augite-andesite tuff of Bail Hill, Sanquhar.*. A specimen taken from the agglomerate exposed in one of the quarries shows under the microscope (No. 6426) that "it is composed of fragments of igneous rocks, which vary somewhat in structure. The greater part of the section is composed of a rock containing large phenocrysts of augite, which is yellowish green in thin section, and phenocrysts of altered plagioclase set in a matrix of microlitic felspar, augite (?), and iron ores. The rock contains vesicles filled with carbonate." So large are some of the masses of diabase-porphyrite in this agglomerate that some of them may really be portions of lava-flows. The microscopic examination of a specimen (No. 5933), from one of these included masses shows "large idiomorphic crystals and grains of augite, measuring a quarter of an inch across, in a dull dark matrix. The ground mass is composed more or less of decomposed plagioclase in the form of short laths; grains of augite and magnetite; chlorite and other decomposition products are present." Like the agglomerate on Bail Hill, Sanquhar, that at Mains Hill points to the explosion of a tolerably basic mass of pyroxenic lava, and from the fact that agglomerate of this peculiar type is restricted to the neighbourhood of Ballantrae it is probable that it may have originated from an independent volcanic centre.

To the north of Mains Hill the augite-andesite tuff is succeeded by lava, protruding at intervals through the drift to within half a mile of Bennane Burn. From the appearance of the red mudstones and cherts in a field about a quarter of a mile S.S.E. of Croseclays, it may be inferred that the volcanic rocks are here repeated by folds. The thickness of the agglomerate of Mains Hill is 800 feet.

The radiolarian cherts can be followed along the strike of the outcrop at Balnowlart about a mile still further to the north-east on the south side of Salachan Hill, as will be shown in the sequel. Though the cherts at Balnowlart are inclined to the N.N.E., and appear there to plunge underneath the Mains Hill

* See the "Ancient Volcanoes of Great Britain," vol. i., p. 195.

agglomerate, it is evident that an inversion of the beds has taken place, for about a mile to the east of Ballantrae, on the banks of the river and by the side of the road, the cherts are repeated by sharp folds, dipping sometimes to the north and sometimes to the south.

Knockdolian Hill, Ballantrae.—The development of agglomerate, breccia, and tuff round independent centres, which is one of the characteristics of the Arenig volcanic rocks of Ayrshire, is strikingly exemplified on the picturesque conical hill of Knockdolian (869 feet), which rises above the northern side of the valley of the Stinchar, two miles from Ballantrae. The slopes of the hill are comparatively rocky, only patches of vegetation occurring here and there. Excellent opportunities are thus afforded for studying the structure of the ground. The river Stinchar—the general trend of which is south-westerly—on reaching Knockdolian Castle, is deflected towards the south round the eastern base of the hill, and thereafter resumes its normal course to the sea (Fig. 107).

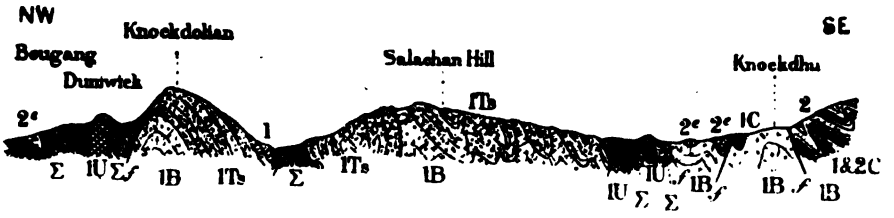


FIG. 107.—Section across Knockdolian from Bougang to Knockdhu, Stinchar Valley, Ayrshire. (Length, two and a half miles.)

1B. Diabase-lavas. 1Ts. Volcanic agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert. Σ. Serpentine. 1U. Intrusive basic rock. 2. Tappins group. 2e. Stinchar limestone and conglomerate. f. Faults.

The geological structure of Knockdolian presents some interesting features.* The hill is composed of bedded lavas and overlying breccias and agglomerates, which are arranged in the form of a great elliptical dome, the long axis of which runs E.N.E. and W.S.W. The core of the arch is formed of bedded lavas, which are confined to a small part of the eastern declivity south of Knockdolian Castle. The lowest bed of the volcanic series here visible consists of a beautiful porphyritic lava, with a dark green base and light green porphyritic plagioclase crystals, closely resembling the Currarie "diabase-porphyrite" already described. It is the most prominent member of the lavaform series, and is traceable for a distance of 400 yards, being followed by fine-grained vesicular diabase-lava like that on the shore at Downan (1 B, Fig. 107).

Overlying the bedded lavas comes a great succession of agglomerates and breccias, arranged in concentric layers which curve

* See view of Knockdolian Hill from the east, "Ancient Volcanoes of Britain," vol. i., p. 194.

round the dome at angles varying from 50° to 60°, and form the greater part of the hill. The characteristic feature of the breccias is the absence of any fine-grained matrix, the rock being wholly composed of angular fragments of vesicular fine-grained lava. Though the average size of the included blocks over much of the hill is tolerably uniform, ranging from a quarter of an inch to two and three inches across, yet the bedding can be determined by the alternating layers of coarser and finer composition. The coarsest materials are found on the western declivity, immediately to the north of Macherwhat Farmhouse, where some of the included blocks measure four feet across. Viewing the agglomerate as a whole, we may observe that the materials become coarser as we pass westwards to the area north of Macherwhat, while the finest materials occur near Finnart Holm, at the base of the eastern slope (1 Ts, Fig. 107).

On the southern declivity, below the crest of the hill, several narrow bands of fine-grained diabase run more or less parallel to the bedding of the agglomerate. These may be intrusive, but this point is uncertain; at anyrate, several thin veins of similar material, not more than two inches thick, traverse the breccias. The microscopic examination of one of these black compact rocks associated with the agglomerate at the roadside north-east of Macherwhat (No. 6418) shows that "felspars, some of which are large enough to be termed microscopic phenocrysts, and magnetite, are the only definitely recognisable minerals. There is also a brown substance. The grain of the rock is so fine that its composition cannot be definitely determined by the microscope."

The peculiar type of angular volcanic breccia, so characteristic of Knockdolian Hill, is likewise found on the south-east side of the valley on Salachan Hill, as will be shown in the sequel. From the evidence now brought forward the agglomerates and breccias of Knockdolian may be conjectured to have been the products of a cinder cone, the materials of which were to some extent assorted under water. From the gradation westwards in the coarseness of the materials, it is probable that the focus of eruption lay somewhere beneath what is now the western slope of the hill. The minimum thickness of the volcanic rocks of Knockdolian Hill is estimated at 800 feet (lavas, 300 feet, agglomerates and breccias 500 feet, the latter increasing in thickness westwards). Along the northern slope of Knockdolian, the lavas and agglomerates are abruptly truncated by a fault which brings intrusive igneous rocks of ultra-basic and basic types (serpentine, gabbro, &c.) in contact with them (Fig. 107).

The horizon of the volcanic rocks of Knockdolian is defined by the occurrence of black shales and black cherts on the banks of the Stinchar, at the south-eastern base of the hill, at the west and east terminations of the alluvial flat named Finnart Holm. Though graptolites have not been obtained from these exposures, the bands are evidently on the horizon of the Middle Arenig black shales at Bennane Head (1 Fig. 107).

Inland Volcanic Area South of Stinchar.—The contemporaneous volcanic rocks on the shore between Dove Cove and Downan Point, which have been already described, stretch inland along the south side of the Stinchar valley, where they form a narrow belt about half a mile broad, extending from the coast-line at Downan to Little Dangart, a distance of eight miles. Although they consist mainly of bedded lavas, some intrusive igneous rocks occur among them between Salachan and Craigneil, to the east of Knockdolian.

In order to understand clearly the geological structure of the volcanic area on the south side of the valley of the Stinchar, it must be borne in mind that there are here two groups of sediments, separated from each other by a marked unconformability, doubtless representing a great interval of time. The older group, comprising red, grey, and black radiolarian cherts and black shales, are conformable with the Arenig lavas; while the younger group, consisting of conglomerates, mudstones, and fossiliferous limestones (Craigneil), belong to the horizon of the Stinchar Limestone series and Benan Conglomerate. Both groups have been affected by a common system of folding, and hence much care is necessary to discriminate between them.

The southern boundary of the volcanic area forms a slightly sinuous line extending from Meadow Park near the shore, by Garphar, Knockdhu, to Little Dangart. Throughout nearly the whole of this distance, it coincides with a fault which brings the overlying strata of Upper Llandeilo age in contact with the volcanic series.

At the south-western limit of the area, near Meadow Park, the relations of the bedded lavas to the Arenig cherts and overlying sediments, as already described, are shown, for a passage upwards from the lavas and cherts can there be traced into the green mudstones and greywackes (Tappins group). For about a mile to the north-east the red mudstones and cherts are visible at intervals in small knobs in the fields, and also in a section where a stream crosses the high road about a quarter of a mile to the north of Burnside, which is the last visible outcrop of them. Thence north-eastwards to the Kilphin Burn, at various spots the lavas are almost in immediate contact with green mudstones and pebbly greywackes without the intervening red mudstones and cherts. It is probable, therefore, that the fault is here of no great amount, being merely sufficient to hide the radiolarian cherts. North-eastwards to the Laggan Burn the rocks are buried under drift, and from the latter point to the Water of Tig, especially near Garphar, the volcanic series is almost in immediate contact with the green mudstones and greywackes. At one locality, in the road at Garphar Farm-house, the strike of the greywackes and shales is oblique to that of the lavas. In Knockdhu Burn the fault is actually visible: jointed ferruginous greywackes are there brought into contact with shattered lavas, the strata being much disturbed and broken on both sides of the dislocation (Fig. 107). Thence to Craigneil

and Strifeland Burn that joins the Stinchar south-east of Colmonell, the evidence is concealed, but in that stream the fault is again seen, bringing greywackes with green and red mudstones against the lavas. From the Strifeland Burn to Little Dangart the junction line is obscured by drift.

From the shore at Downan to Heronsford, on the Water of Tig, the bedded lavas, as seen in the fields and in burns that drain into the Stinchar, consist of vesicular diabase with pillow-structure, of the same general type as those on the shore already described (Fig. 106). From Heronsford east to Craigneil Castle, the geological structure is somewhat complicated, owing to the infolding of a narrow belt of fossiliferous limestones, mudstones, and conglomerates (Stinchar Limestone and Benan Conglomerate), which are in immediate contact with the volcanic series and radiolarian cherts.

To the south-east of Knockdolian Castle, the Salachan Hill (Fig. 107) rises to a height of over 300 feet from the alluvial terraces on the south bank of the river, where the Arenig cherts and black shales are associated with lavas and volcanic agglomerates. The relations of the strata are represented in (Fig. 107). At the bend in the Stinchar opposite Finnart Holm, black cherts are exposed on the east bank of the river, probably a prolongation of the outcrop about half a mile to the south-west, at the southern base of Knockdolian Hill. These cherts are followed southwards by volcanic agglomerates containing fragments of chert, while the north-west slope of Salachan Hill presents volcanic breccia and agglomerate of the same type as those of Knockdolian Hill, being made up of angular and sub-angular fragments of fine-grained diabase. About the level of the 200-feet contour line, the agglomerate is succeeded by fine-grained vesicular diabase-lava, probably occurring in a fold. Southwards the lava is succeeded, at a level of 300 feet, by more volcanic breccia of the Knockdolian type, with, however, an ashy matrix. Advancing southwards across the hill we find breccia of a more basic type, till in the fields on the southern slope two outcrops of vesicular lava with pillow-structure occur, separated from each other by volcanic breccia with fragments of black chert. At the more southerly exposure, in a small quarry in a field, the rock, though highly decomposed, shows the characteristic pillow-structure in small oval-shaped masses. Here the evidence is partly concealed under drift, but the exposures in the adjoining fields indicate that the lavas and volcanic breccias are here associated with cherts and black shales. The red cherts of this locality (about a third of a mile E.N.E. of Salachan Farm-house) are coated and veined with hematite to such an extent as to have led to the belief in the existence here of a rich vein of iron ore.

South-eastwards on the high-road leading to Colmonell, the radiolarian cherts are to be seen on the south side of a small wood, close to a mass of gabbro. They are slightly granulitised, probably owing to contact metamorphism produced by the adjacent eruptive rock. On the south side of the gabbro mass

a belt of serpentine is well seen in quarries at the roadside. Southwards gabbro again appears, followed by serpentine at a bend in the burn of Knockdhu. Southwards, in that stream beyond a blank in the section, the Arenig lavas appear, followed by conglomerate, which, from the included pebbles, is evidently on the horizon of the Benan conglomerate. Within a short distance the lavas reappear, followed unconformably by conglomerate, green mudstones, and grits. The blocks of limestone in the conglomerate have yielded specimens of *Girvanella*. Here the burn flows through a rocky gorge, at the head of which a fault brings the unconformable fossiliferous mudstones and grits in conjunction with the radiolarian cherts and mudstones of Arenig age to the south. Higher up the stream the lavas reappear, till at a point about 500 yards above Knockdhu Bridge the fault occurs that marks the southern limit of the volcanic area.

Though in this section but a small development of the strata rests unconformably on the volcanic rocks and radiolarian cherts, yet they can be traced for some distance to the south-west and north-east, as will be shown in the sequel.

The narrow strip of Arenig volcanic rocks visible in the Craigneil and Strifeland Burns, between two faults, is composed mainly of diabase-lavas with pillow-structure. These rocks are well seen also on the rising ground immediately to the south of the fossiliferous Stinchar Limestone group at Craigneil Farmhouse. About midway between the two faults which bound the narrow volcanic band in the Strifeland Burn, a bed of tuff may probably lie near the top of the volcanic series.

Colmonell to Aldons.—A narrow belt of volcanic rocks lying between two faults stretches from the village of Colmonell along the northern slope of the Stinchar valley to Aldons, where it crosses the river in the direction of Pinmore Mains (Sheet 8 of Survey Map). Along the southern margin of this volcanic band, conglomerates, sandstones, and mudstones (Kirkland and Benan series) are brought into conjunction with the lavas; while the fault on the north side brings intrusive igneous rocks, Arenig lavas, and the Aldons (Stinchar) Limestone and conglomerate successively in contact with the volcanic rocks.

Throughout this area, the volcanic rocks consist chiefly of lavas showing pillow-structure, which are well displayed in the glen near Poundland and in the ravine west of Daljarrock. An interesting development of agglomerate and breccia may be seen on the Craig Hill and Prieston Hill, about a mile north-east of Colmonell village, where these pyroclastic materials are associated with black shales and radiolarian cherts. This agglomerate, which contains blocks of volcanic rocks, together with pieces of chert and black shale, set in a green matrix, seems to lie in a series of compound isoclinal folds, dipping to the south-east, the best exposure being on the southern slope of Craig Hill. The rock is underlain by fine-grained diabase-lava, showing pillow-structure. At several places along the junction-line

between the agglomerate and lavas, a thin band of black shale, in places much corrugated, makes its appearance. It is seen near the ruins of a shepherd's house about 400 yards N.N.W. of Craig Farm, and in greater development about 100 yards further north, near a stone fence. The radiolarian cherts and red mudstones, some of which are nodular and others more massive, form four isolated patches on the south slope of Prieston Hill, about the level of the 500-feet contour line, tha largest outlier measuring about 400 yards in length.

From the lithological characters and order of arrangement of the volcanic rocks and associated sediments on the Craig and Prieston Hills, there can be little doubt that we have here representatives of the sequence already described as occurring at Bennane Head. No fossils have yet been obtained from these bands, but it is highly probable that a prolonged search would result in the discovery of Middle Arenig graptolites in the black shales.

Further to the north-east, on Glessal Hill and Bargain Hill, lenticular masses of agglomerate occur, which are not found in the intervening gorges, and may therefore be outliers of more widespread deposits. The old limestone quarry at Daljarrock seems to have been opened in a vein rock along the line of fault that separates the conglomerates and sandstones of the Kirkland series (Upper Llandeilo) from the lavas. A specimen (No. 6437) of dark massive green rock from this quarry showed no definite structure under the microscope, save that it was originally an igneous rock with lath-shaped felspars.

Aldons Hill.—To the north of the area described in the foregoing paragraphs, a patch of ground about a square mile in extent is occupied chiefly by bedded lavas. It comprises the Aldons Hill, with parts of the Breaker Hill and Fell Hill. The lavas consist mainly of the vesicular diabase type, showing pillow-structure, but occasional flows are composed of diabase-porphyrite. The northern slopes of the Aldons and Fell Hills, overlooking Chapelcroft, are marked by a band of fine-grained flinty rock, that weathers white. To the south of Chapelcroft, where it occurs in knolls east of the burn, this rock is very compact like chert, and when traced about a quarter of a mile to the west, becomes vesicular. Microscopic examination does not furnish any evidence as to its origin, but it may probably be one of the fine-grained lava-form rocks. A lenticular mass of coarse agglomerate occurs on knolls between the Breaker Hill and Bargain Hill. The lavas of the small tract now referred to are bounded on the east and north sides by the Benan conglomerate, which there rests unconformably on the volcanic series, and on the west side by one of the largest intrusive masses of serpentine.

Central Volcanic Area between Bennane Head and Lochton.—The central area of bedded volcanic rocks now to be described forms a narrow belt varying from half a mile to a mile in width, and is bounded on the north and south by the

two parallel intrusive masses of serpentine. It stretches inland from Bennane Head, by Knockormal Hill and Carleton, to Lochton, in the valley of the Lendal Water, a distance of a little more than six miles. The radiolarian cherts, the Arenig black shales and underlying agglomerates, the diabase and diabase-porphyrite lavas, which are so typically developed on the shore between Bennane Head and Balcreuchan Port, are all met with in this central area, where they are repeated by various folds. It is true that, owing to cleavage and lines of movement traversing the strata, especially the black shales, their stratigraphical horizon has not been definitely proved by fossils within this district, but the general sequence of rocks, taken in connection with the fact that the cherts, black shales, agglomerates, and lavas of the inland area occupy the same series of compound folds as those at Bennane Head, points to the conclusion that the rocks are of the same age.

The tract immediately to the east of Bennane Head, and along the course of Bennane Burn, is largely covered with drift, but agglomerate occurs in the fields north-east of Balcreuchan Farmhouse, near Troax, and again at South Ballaird, near the source of the Bennane Burn, where it is associated with vesicular diabase-lava. In the field to the east of South Ballaird Farmhouse, along the course of a footpath, and in adjacent quarries, black shales, grey shales, and cherts are reduplicated by folds. On a small hill at the north-east corner of this field, agglomerate is exposed at the surface, followed by black shales at the base of the slope and in the heart of the mass to the E.N.E. of South Ballaird Farmhouse, where they appear to lie in a fold of the agglomerate. Again, on the western slope of the closely adjacent Lochton Hill, a mile and a half south of Lendalfoot, black shales are repeated by sharp folds like the bands to the west. The volcanic breccia is traceable northwards from Lochton Hill for a few hundred yards to Knockormal Hill, and eastwards to the Moak Hill, where it appears to rest on diabase-lavas with pillow-structure. The junction-line between the lavas and the agglomerate is a complicated one, inasmuch as the two groups of rock form a series of insoculating folds. In like manner, where the agglomerate becomes fine-grained on the south slope of Lochton Hill, the isoclinal foldlng of the tuff and the black shales is evident.

The hollow to the east of Knockormal Hill is covered with drift, but on Knockdaw Hill, to the S.S.W. of Millenderdale, and in the burns draining the north-west slope of that eminence, there is a fine development of lavas, composed mainly of vesicular diabase, and in places of diabase-porphyrite. Thin lenticular masses of blue limestone in one of the burns south of Knockdaw Castle resemble the sedimentary limestone that fills the interstices between the spheroids of lava on Downan shore, south of Ballantrae. The relation of the lavas to the intrusive gabbro and serpentine along the southern slope of Knockdaw Hill will be described in the sequel (see p. 471).

The northern portion of the central area of volcanic rocks presents several features of special interest. Skirting the shore to the south of Lendalfoot, the lower portion of the western declivity of Carleton Hill is occupied by serpentine, while the remainder of the ridge is formed of a complex of diabase-lavas and tuffs with black shales, epidiorite, hornblende-schist, and flaser-epidote rocks, the whole being traversed by a later series of dolerite dykes, older than the Benan Conglomerate and Stinchar Limestone, and a few basalt dykes, probably of Tertiary age. The lithological characters, exact limits, and relations of some of the members of this complicated area might well furnish materials for more detailed investigation.

On the south-east slope of the hill, about the level of the 500-feet contour line, a band of black shale can be traced for some distance, which, over part of the outcrop, is so cleaved that fossils would be difficult to obtain from it. At the southern limit of Balsalloch Hill, however, a continuation southwards of Carleton Hill, the beds are not deformed, and might be expected to yield graptolites, but a short search has so far not been successful. The soft black shales are there associated with black cherts or flinty shales, like the Middle Arenig band at Bennane Head, and rest on tuff and diabase-lava, but along their line of outcrop, on the south-east slope, masses of gabbro occur close to them. The diabase-lava is traceable along the south-east slope of Carleton Hill, but along the top and western slope the rocks have undergone considerable change. One of the recognisable lavas of the porphyritic type from this hill (No. 5923) shows, in the hand specimens, "conspicuous phenocrysts of white felspar in a compact dark green matrix," and under the microscope "large and small phenocrysts of felspar and small phenocrysts of augite in a brown matrix, which is not isotropic."

Along the western slope of Carleton Hill, above the margin of the serpentine, a remarkable series of platy rocks of peculiar lithological characters dips at high angles to the north-west, and may be studied in many excellent exposures. They are traversed by numerous dolerite dykes running in a westerly direction. They have a dark purple and green tint, are very fissile, and break under the hammer into small angular fragments. At one point, high up the slope south of Carleton Fishery, they contain a thin lenticular band of blue crystalline limestone. Generally they are fine-grained; indeed, in some instances the constituents cannot be definitely determined under the microscope, but nearly all the rocks show marked flaser structure. They have been traced along the border of the serpentine area from the west slope of Carleton Hill, across the Lendal Water by Laigh Knockclauch to Lochton, a mile and a half south of Byne Hill, where the rocks have been subjected to considerable dynamic movement. Some of these platy rocks contain epidote in considerable quantity, interleaved in green bands of hornblende-schist.

A specimen taken from the north-west face of Carleton Hill (No. 6501) shows under the microscope "that the dark portion of

the rock possesses marked parallel structure due to shearing, but is of so fine a grain that the minerals cannot be definitely determined. The light yellowish-green bands contain epidote, a pale brown garnet, and possibly malacolite." Another specimen interleaved in the platy rocks from the same place (No. 7783) displays "a foliated aggregate of pale green hornblende, showing marked signs of pressure fluxion. Some felspar was probably present in the original rock, but it is not now definitely recognisable." A third specimen from the same series (No. 7784) exhibits "'eyes' of felspar in a fine-grained matrix of hornblende-schist." Mr. Teall is inclined "to regard this rock as a porphyritic dolerite or diabase modified by dynamic action. The hornblende is green, not brown." Still another microscopic section, taken from an exposure in the Lendal Water behind the gamekeeper's cottage (No. 6507), "contains streaks and flaser rich in epidote," similar to No. 6501. What the precise origin of these flaser-epidote rocks may have been is at present uncertain, but this much is clear, that the planes of schistosity must have been developed in them and in the associated hornblende-schist before the intrusion of the dolerite dykes, which are older than the Stinchar Limestone and the Benan Conglomerate (Upper Llandeilo). In the sequel we shall show that the south-eastern margin of the serpentine mass between Carleton Hill and Lochton has been a line of movement, and that these platy rocks may have had their schistose planes impressed on them by that movement.

In the hollow between Carleton Hill and the intrusive mass of gabbro on Knockormal Hill, the volcanic rocks consist mainly of bedded lavas with occasional bands of agglomerate. About a third of a mile to the south of Carleton Castle (in ruins), in a road cutting by the side of Little Carleton Burn, black shales with a south-easterly dip, rest on tuff, containing fragments of black shales; while underneath the tuff lies some compact diabase-lava. It is highly probable that this outcrop of black shales may be an exposure of the Middle Arenig band of Bennane Head. This suggestion seems to be confirmed by the fact that in the small burn that joins the Lendal Water at Cundry Mill, to the east of Carleton Mains, red mudstones and radiolarian cherts appear in association with agglomerate. These rocks are met with about 400 yards up the stream, while near the foot of the same burn lavas are associated with the red cherts and mudstones.

Near the farm-steadings of Knockdaw and Laigh Knockdaw, south of the Lendal Water, Arenig lava, both of the porphyritic and diabase types, is exposed in the burn sections and in knolls in the fields. These outcrops are of importance, since they help to fix the position of the fault that brings in the younger fossiliferous rocks of the Girvan series to the east. Fine-grained lavas are also visible in quarries behind Barclewan Farmhouse, on the north bank of the Lendal Water. A beautiful example of the porphyritic type is to be found on the hill-top above Pennyland

Wood, about 500 yards to the north of Barclewan, where large porphyritic felspars, sometimes an inch in length, project on weathered surfaces. The lavas are here traversed by basalt dykes running in a north-west and south-east direction. About half a mile to the west of this hill-top, debris of red mudstones and cherts is ploughed up in the fields, on the strike of the outcrop in the small burn that falls into the Lendal Water south of Cundry Mill, above referred to.

Along the south-east margin of the serpentine area, in the direction of Knockbrake, Laigh Knockclauch, and Lochton, several sections in streams which drain the hill slope west of the Lendal Water, display lavas, tuffs, black shales, and flaser rocks. About 300 yards west of the ruins of Knockbrake, diabase-lava, black shale, and mudstone occur on knolls to the south of the serpentine. Again, in a small burn west of Laigh Knockclauch, the rocks bordering the serpentine are laid bare for a distance of 200 yards. At the mouth of this streamlet, a vein of serpentine is exposed, followed by black shales yielding fragments of *Tetragraptus* and *Climacograptus*, and by porphyritic diabase-lava. Further up stream the rocks display under the microscope (Nos. 7800, 7801) the structure of intrusive rocks rather than that of lavas, the augite being quite fresh. Near the margin of the serpentine, compact platy rocks are met with, a specimen of which (No. 7803), when examined microscopically, is found to be a fine-grained hornblende-schist containing much epidote.

Similar evidence of flaser-structure occurs on the hill slope about 300 yards further north, and a quarter of a mile south-west of Loch Lochton, where a lenticular strip of garnetiferous hornblende-schist lies near the margin of the serpentine, but is apparently surrounded by that rock. A specimen taken from this exposure, at a point about 600 yards north-west of Laigh Knockclauch (No. 7804), shows "brown hornblende, malacolite, and felspar." Another specimen, collected from the same band of hornblende-schist, a few yards to the west (No. 7805), exhibits "streaks and flaser of epidote in a very fine-grained matrix showing pressure fluxion. The matrix is similar to that of No. 7802. It is a rock which has been subjected to considerable dynamic action, and the flaser of epidote may possibly represent porphyritic crystals of felspar which have been epidotised."

In the Lochton Burn serpentine is seen for about 300 yards above Laigh Knockclauch, followed by an intrusive basic mass like gabbro. Next come black shales, visible at a waterfall, succeeded by alternations of lavaform rocks and flaser-rocks. Along the road that skirts the west side of Loch Lochton, several outcrops of tuff or agglomerate with intercalations of black shales are met with, one in a small quarry due west of the south end of the loch. The tuff, agglomerate, and black shale are much shattered, altered, and injected with igneous material.

Similar evidence is obtained in the small burn that passes Lochton Cottage and joins the Bynehill Burn. Behind the ruins

of the shepherd's house at Lochton, tuffs and black shales are visible, followed by shattered and altered lavas, which are succeeded in turn, as we pass north-westwards, by flaser-rocks, highly sheared, and in contact with the serpentine, the whole section being only about 100 yards in breadth. Between Lochton and Balkeachy, porphyritic lavas are visible on knolls near the stream, and highly sheared rocks are seen at a sharp bend in the burn itself. The physical relations of these rocks, however, are entirely obscured by drift and alluvium. The position of the boundary fault along the south-east margin of the serpentine is indicated by shattered exposures of that rock in the Bynehill Burn, about 400 yards west of Balkeachy Farm steading. Here an old shaft was sunk in search of copper ore.

From the foregoing evidence it is clear that, along a line extending from Carleton Hill to Lochton, south of Byne Hill, black shales occur in association with agglomerate, tuff, and lava, while near the margin of the serpentine a series of highly sheared materials, including flaser-epidote rocks, has undergone much deformation. Though the black shales of Lochton and Carleton Hill have not as yet yielded graptolites, they are provisionally correlated with the Middle Arenig band at Bennane Head, owing to the occurrence of *Tetragraptus* in black shales at Laigh Knockclauch (p. 458).

Northern Inland Volcanic Area, including Pinbain Hill.—The remaining district of the main volcanic area of Ballantrae which now falls to be described includes a small triangular tract, lying to the east of the shore-section already described between the mouth of the Pinbain Burn and Kennedy's Pass. The bedded lavas and tuffs visible on that part of the shore when traced inland for a short distance, are seen to be bounded on the north by the Benan Conglomerate, and on the south and east by ultra-basic and basic intrusive rocks.

The beautiful diabase-porphyrite lava visible on the shore south of Stockinray Bay forms the greater portion of Pinbain Hill, and is prolonged eastwards into Kilranny Hill, where it forms the highest part of the ridge. Along the south-east side of Pinbain Hill it lies immediately in contact with the most northerly mass of serpentine, but north-eastwards towards Kilranny Hill the strike of the beds turns more to the north, and a gradually thickening wedge of agglomerates, tuffs, and ashy sediments comes in. These rocks are identical in character with those found on the Pinbain shore to the north of the serpentine. The pyroclastic materials and ashy sediments dip at high angles to the south-east, and become more fine-grained in that direction near their point of junction with the intrusive rocks; indeed, some of the finer bands closely resemble the ashy shales which yield Middle Arenig graptolites in the road-cutting on the Pinbain shore (p. 444), and there can be little doubt that they occupy a similar horizon. These beds are also visible near the head of a burn that drains the north-west slope of the Grey Hill, and falls into the sea near the fourth milestone from Girvan.

The west side of Pinbain Hill affords a good section across the strike of the beds in a burn that drains its slopes, and also those of Kilranny Hill. In the burn, above the point where it is crossed by the old road, the agglomerate, so well developed in Stockinray Bay, is exposed, while the beautiful porphyritic lava (diabase-porphyrite) which forms the northern headland of that bay is also seen in the same burn at the old road. The red cherts occur to the north-east of this section.

Small Inliers of Arenig Volcanic Rocks near the Main Volcanic Area of Ballantrae. — To the east of the main volcanic area of Ballantrae, several patches of Arenig volcanic rocks form "inliers" among the younger unconformable fossiliferous strata of Silurian age. Of these, the most important is met with on Daldowie Hill, on the south side of the Water of Assel, where the lavas, tuffs, intrusive gabbro, and associated cherts form a patch about a mile long and a third of a mile broad (Sheet 8). From the disposition of the overlying fossiliferous sediments of the Stinchar Limestone group, it would appear that the rocks of this "inlier" form a compound anticline, arranged in the following descending order: (1) Cherts and jasper containing radiolaria with calcareous knots; (2) basic lavas showing pillow-structure; (3) fine tuffs or ashy sediments; (4) volcanic agglomerate.

The volcanic agglomerate or coarse breccias in a narrow strip towards the north-east margin of the area, are followed southwards by a band of finer tuff or ashy shales, and these by a broad zone of diabase-lava, in which the radiolarian chert and jasper occur. The volcanic rocks are pierced by dykes and bosses of gabbro, which locally harden and alter the agglomerate and breccia. Blocks of gabbro occur in the adjacent conglomerates associated with the Stinchar Limestone group, but they have not been detected in the volcanic agglomerates.

In several places on Daldowie Hill and Shalloch Hill, ribs and bands of hard purple chert and jasper occur, which contain radiolaria. Pieces of these cherts are common in the adjacent conglomerates of the Stinchar group. At one spot (marked "Whinstone Quarry" on the six-inch map), at the west end of Shalloch Hill, a peculiar rock, quarried for dyke-building, consists of red cherts and jasper, brecciated in place and recemented by red calcite. The crystalline limestone at this place contains oval masses and knots of a rock resembling serpentine or other ultra-basic material, but microscopic examination throws no light on its orgin.

A few yards to the south of the inlier above-mentioned, a small patch of volcanic tuff, charged with blocks of diabase-lava, is visible near the head of the Minuntion Burn, associated with the Benan Conglomerate and Stinchar Limestone.

In the south quarry nearest the Lane Toll at Craigwells, 2½ miles north-east of Daldowie Hill, decomposing gabbro rises from underneath the Stinchar Limestone group; further to the south-west a small mass of ultra-basic rock is likewise exposed near the limestone.

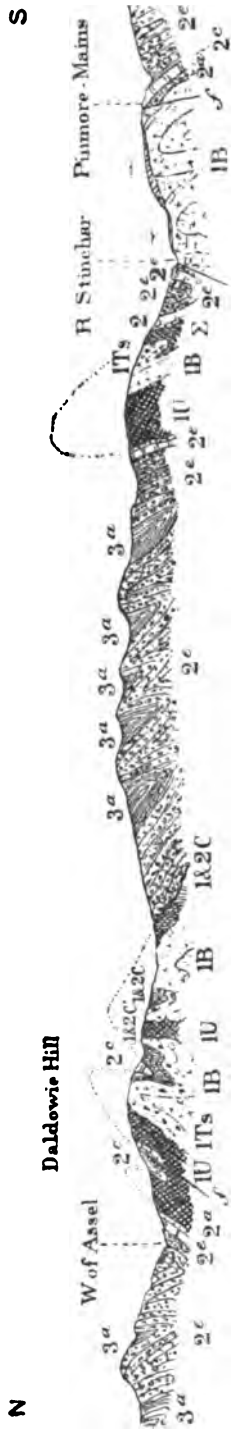


Fig. 108.—Generalised Section from Water of Assel across Daldowie Hill to Pinmore Mains (South Ayrshire), to show relation of Inliers of Arenig Volcanic Rocks to overlying Sediments. (Length, three miles.)

1B. Lavas. 1Ts. Agglomerate. 1&2C. Radiolarian chert. 2. Serpentine. 1U. Intrusive basic rock. 2a. Kirkland conglomerate. 2c. Stinchar limestone. 2e. Benan conglomerate. 3a. Balclatchie beds. f. Fault.

West of the Girvan and Portpatrick railway, small bosses of Arenig lavas, with intrusive gabbro, project from the surface in the fields to the north of Meikle Letterpin. Small exposures of the Benan Conglomerate are found near the lavas, but the actual junction of the two rocks is not seen.

Another small inlier of agglomerate is visible on Glendrissock Hill, about half a mile to the south-east of the farmhouse of that name. On the south side of the hill black shales and cherts occur, not far to the north of the outcrop of the Stinchar Limestone between Pinmacher and Laggan, which may be in the horizon of the band at Bennane Head that yields the Middle Arenig fauna.

Craighead (Sheets 8 and 14 of the Survey Map).—The largest and most important inlier of the volcanic series occurs at Craighead, on the north side of the Girvan valley. Between Killochan Station and Craighead limestone quarries, it measures about a mile in length, and between the Girvan railway and the top of Craighead Hill, about half a mile in breadth. This area

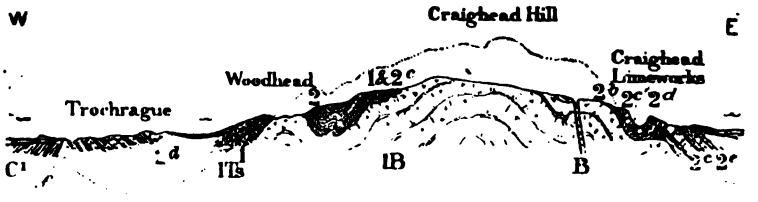


FIG. 109.—Section across Craighead Inlier.

1B. Arenig lavas. 1&2C. Radiolarian cherts. 2. "Tappins group." 2b. Kirkland conglomerate. 3c. Stinchar limestone. 2d. Graptolitic mudstone. 2e. Benan conglomerate. C¹. Lower old red sandstone.

seems to be wholly composed of vesicular diabase-lava with pillow-structure, which is well seen in the railway cutting at Killochan Station, in the cutting in the wood near the Craighead limestone quarries, in knolls in the wood north-east of Woodhead Farmhouse, on the top of Craighead Hill, and in small rocky knolls in the cultivated ground to the north-west of that hill (1 B, Fig. 109).

On the south-east side the volcanic area is truncated by a fault which brings down the Carboniferous rocks, and at the eastern corner the Arenig lavas are unconformably overlain by the Craighead Limestone series, which will be described in the sequel. On the north-west side, however, the lavas are succeeded by red radiolarian cherts and green mudstones, visible in the road leading to Barneil Farmhouse and in the fields and wood about a quarter of a mile east of Woodhead. The cherts are vertical or highly inclined, and are immediately followed by green mudstones, shales, and greywackes resembling the "Tappins group" of the Stinchar valley. The radiolarian cherts cannot be traced round the northern margin of the inlier towards

Craighead; indeed, judging from the surface-features in that area, the lavas seem to be abruptly truncated by a fault, but the overlying strata north of Craighead Hill are buried under drift.

In a quarry in the small wood at Woodhead Farm steading, red cherts, black shales, and black cherts appear in association with volcanic agglomerate, and a few yards to the east of the wood there is an exposure of basic igneous rock. Though only *Climacograptus* has been got from these black shales, yet their lithological characters and their occurrence with agglomerate suggest the probability that they lie on the horizon of the Middle Arenig Shales at Bennane Head. The small outcrops of volcanic rocks evidently belong to a separate inlier from that of Craighead (1, 1 Ts, Fig. 109). About a mile to the north-east of the Craighead limestone quarries, at Blaweary, still another inlier of diabase-lava is traceable for about 200 yards, in association with the limestone of the Craighead series.

Inliers South of the Stinchar Valley near Barr (Sheet 8).—On the south side of the valley of the Stinchar, in the neighbourhood of Barr, various arches of Arenig lavas and radiolarian cherts occur as inliers in the green mudstones, shales, and greywackes of the Tappins group, followed in normal sequence by the greywackes, shales, and grits of the Southern Uplands. Indeed, the sections now under consideration are identical with those on the shore at Brakness Hole and Shallochbraik, south of Currarie (p. 424), which show a passage upwards from the lavas and cherts to the overlying mudstones, shales and greywackes.

A glance at the published map (Sheet 8) will show the various lenticular bands of Arenig chert with cores of lava which have been traced at intervals from the head of Muck Water north-east by the Howe of Laggan to Aldinna, in the valley of the Stinchar, a distance of about seven miles. These outcrops are mostly isoclinal arches, and resemble many similar lenticular folds of the lavas and cherts along the northern margin of the tableland between Loch Doon and the Lammermuir Hills. The lavas are traceable by means of small bosses across the moor from the head of the Muck Water towards the Gregg Water, re-appearing in a small tributary of the latter stream, on the col of the Howe of Laggan, and on the slope of the Pinbreck Hill, which is about a mile from Aldinna, in the valley of the Stinchar. They consist of fine-grained green diabase with small rounded vesicles resembling the vesicular diabase type at Downan. In each case they are associated with red radiolarian cherts which pass upwards into green mudstones, shales, and greywackes. The section that best shows the relation of the lavas to the cherts may be seen in a small tributary of the Gregg Water, about 200 yards to the south-west of Darley shepherd's house. Near the foot of this stream a fine exposure of slaggy diabase-lava forms the core of the arch, surrounded by red cherts with radiolaria and green mudstones, the beds being isoclinally folded to the south-east. The relation of the Arenig cherts to

the green mudstones, shales, and greywacke bands of the "Tappins group," is admirably seen in a small tributary of the Stinchar, on the north side of the valley and to the east of Tappins Hill. At the foot of this stream, the radiolarian cherts dip towards the south-east, while up stream the barren beds of the "Tappins group" are well displayed.

About a mile and a half to the north of the strike of the series of arches just referred to, and within half a mile of the river Stinchar at Dularg, a small exposure of Arenig lava is associated with red cherts on the hill to the east of Traboyack Farmhouse.

CHAPTER XX.

THE GIRVAN DISTRICT—*continued.*

INTRUSIVE IGNEOUS ROCKS.

THE intrusive rocks associated with the Arenig volcanic series are admirably displayed in the region between Girvan and Ballantrae. They consist of ultra-basic, basic, and acid masses, including serpentine, olivine-enstatite rock (saxonite), hornblende-picrite, pyroxenite, gabbro, epidiorite, dolerite, and granite. But while the variety of these intrusive types is strikingly exemplified throughout the region, the relations which they respectively bear to each other in the field are in many places obscure. For over much of the area, owing partly to the more rapid decomposition of the serpentine and partly to the covering of superficial deposits, the lines of contact between that rock and the other igneous masses are not visible. Further, planes of schistosity have been locally developed in some of the intrusive rocks, whereby the serpentine has been rendered schistose, the gabbro and hornblende-gabbro have been foliated, and the epidorite has been converted into hornblende-schist. Lines of movement traceable for miles have in one or two instances destroyed the evidence of the original relationship of the serpentine to the adjacent rocks, the resulting flaser-structures being apparent in the field, and confirmed by microscopic examination of the rocks. For these reasons it is difficult in many cases to determine the relations and sequence of the intrusive rock masses.*

The detailed mapping of the region, however, leads to the belief that the more highly basic rocks, comprising serpentine, olivine-enstatite rock, hornblende-picrite, gabbro, and other compounds, which are the most abundant, were the earliest to be injected. They pierce the lavas, tuffs, and agglomerates, while on the shore the serpentine is in visible contact with the Middle Arenig black shales and radiolarian cherts. In some of the exposures, where the junction between the serpentine and the less basic rocks is laid bare, the latter do not show any evidence of having been intruded into the former; indeed, their relations, judging from certain exposures, are such as to suggest that some of the rock types may be different modifications of the same original basic magma. But while this relation is probable, it is

* A short summary of the results of the re-survey of these plutonic rocks is given by Sir A. Geikie. "The Ancient Volcanoes of Great Britain," vol. i., p. 200.

nevertheless clear that the complex basic masses, together with the interbedded lavas and agglomerates, have been subsequently invaded by irregular dykes or veins of dolerite and gabbro, which present chilled margins at their lines of contact with the surrounding rocks.

Between Girvan and Ballantrae the intrusive rocks form two prominent belts, which run generally along the strike of the volcanic series, black shales and cherts. The northern one occupies three miles of the coast line between Pinbain Burn and Burnfoot, south of Lendalfoot, and extends inland by Lochton to Byne Hill; while the southern is traceable from the raised beach south of Bennane Head eastwards by the slopes of Knockdolian and Balhamie Hill to Millenderdale. Small isolated basic masses occur beyond these limits, as, for instance, on Knockormal Hill, at Ballantrae Castle, and other places.

On referring to the Geological Survey Map (Sheet 7) of the region, it will be seen that serpentine occupies by far the largest part of the area covered by the intrusive rocks. Though owing to the mantle of superficial deposits, the boundaries of the respective igneous masses shown on the map are in some instances conjectural, yet the more basic rocks usually form more or less lenticular bands or bosses in the midst of the serpentine areas, protruding at the surface as rocky knolls frequently bare of vegetation. We shall therefore begin with the description of the development of the serpentine in the two prominent belts just mentioned, proceeding thereafter to deal with the masses of gabbro, epidiorite, and other intrusive materials of a less basic kind.

Serpentine.

Southern Area.—This belt, which extends for a distance of seven miles from Drummore shore south of Bennane Head to Millenderdale, with an average breadth of about a mile, is mainly occupied by serpentine, which generally occurs in the massive form, though at certain localities foliated varieties are likewise met with (Fig. 110). One of the best places for studying the massive type of serpentine is on Balhamie Hill, about a mile to the north of the village of Colmonell, where it is exposed on the southern slope and in streams that drain the declivity. The lithological and microscopic characters of this type, as developed on this hill, have been well described by Professor Bonney, who clearly recognised the igneous origin of the serpentine and its resemblance to the type of that rock seen to the north of Cadgwith, Cornwall. He refers specially to an exposure in a pit near the roadside, about three-quarters of a mile from the village of Colmonell, and gives the following description of the rock.* The serpentine, "on old surfaces, assumes the same rugged grey-brown aspect as that at the Lizard; its fracture is sub-

* "On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast," Quart. Jour. Geol. Soc., vol. xxxiv., p. 770.

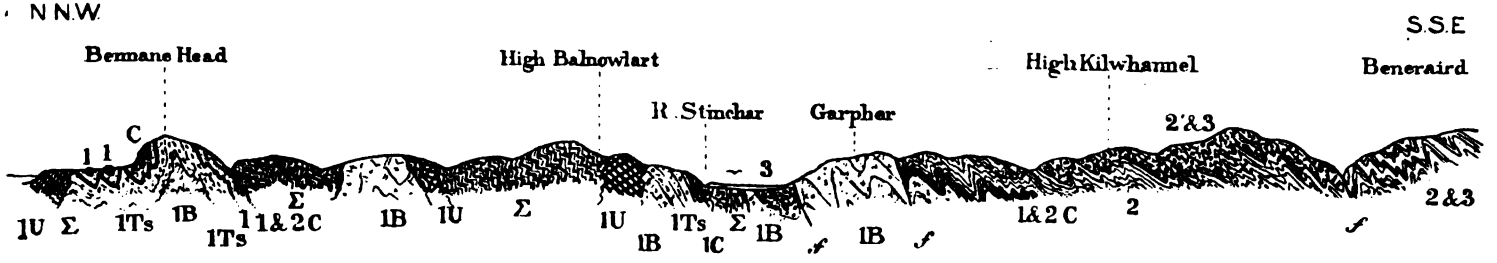


FIG. 110.—Generalised Section across the Ballantrae Volcanic Area from Bennane Head to Beneraird. (Length, six miles.)

1B. Lavas. 1Ts. Agglomerate. 1. Arenig black shale. 1&2C. Radiolarian chert., Σ. Serpentine. 1U. Intrusive basic rocks (Silurian). 2. "Tappins" group. 2l. Glen App conglomerate. 2&3. Llandeilo-Caradoc. 2e. Stinchar limestone group. ~~ Alluvium. f. Faults.

conchoidal. The ground mass is a deep black, weathering to a pale grey-green. It is full of crystals of glittering bronzite, just like those in the Cadgwith rock. A detailed description of the microscopic structure is needless, for what I have written of that will apply here almost word for word, the only difference being that, in the specimen examined, the conversion of the olivine into serpentine, stained and clothed with granules of black ferric oxide, exhibit a rude parallelism over part of the slide. The bronzite also in this rock is a little more altered than it is at Cadgwith; some grains contain numerous ferruginous microliths. There is in the slide a grain or two of a dark brown mineral, possibly picotite. I have not the slightest doubt that this is an altered olivine-enstatite rock."

In this quarry near Colmonell, Professor Bonney observed an irregular vein of a greenish mineral, about four inches thick, which was analysed by Mr. Houghton, who thus reported on the specimen sent to him for examination.* "This rock appears to coincide in all its properties, both chemical and physical, with the mineral chonicrite, which is stated by Dana to be found associated with serpentine in Elba. It differs in having less Si. and more Fe."

The observations of Professor Bonney regarding the petrographical characters of the serpentine of Balhamie Hill have been confirmed during the recent revision by the Geological Survey. The glistening crystals of rhombic pyroxene, or its alteration product, bastite, set in a black or dark green matrix, form one of the characteristic features of the rock as developed on this hill. Two specimens collected during the recent revision from this locality are thus described by Mr. Teall. The first (No. 6428) displays in the hand specimen "crystals of bastite, giving a brilliant lustre from their cleavage surface, and often measuring more than a quarter of an inch across, which are set in a compact dark green matrix. Cleavage flakes of the bastite, detached with a knife, show the characteristic negative bisectrix in convergent polarised light. Under the microscope the large plates of bastite are found to be irregular in form. They lie in a matrix traversed by anastomosing veins of dusty magnetite, and possessing the mesh structure of serpentine derived from olivine. The rock is a serpentine derived from a saxonite (harzburgite of Rosenbusch)." The second (No. 6429) shows, in the hand specimen, "small irregular patches of picotite (hardness greater than that of quartz) in a compact dark greenish matrix. Under the microscope it shows serpentine derived from olivine, together with irregular masses of picotite, which are only transparent in very thin sections, and then appear a deep rich chesnut brown. The rock is a serpentine derived from Dunite."

On the moor to the north of Poundland Hill, two miles north-east of Colmonell, massive picotite occurs in the serpentine. The best locality is about 300 yards north from the margin of the

* Quart. Jour. Geol. Soc., vol. xxxiv., p. 772.

serpentine area, and near the source of the Poundland Burn, where several veins have been observed. A specimen collected here (No. 6449) is described by Mr. Teall as "massive picotite (sp. gr. 3.68), containing a few irregular white patches, which apparently represent altered felspar. Under the microscope, the picotite is chesnut brown in very thin section. The supposed felspars have been converted into a pseudophite-like substance, which is found also in narrow veins traversing the massive picotite."

The following analysis of the rhombic pyroxene, which forms such a conspicuous feature in the Ayrshire serpentine as developed on Balhamie Hill, Knockdaw Hill near Lendalfoot, and other places, has been made by Professor Heddle: *

SiO_2	37·776
Al_2O_3	2·123
Fe_2O_3	5·069
FeO	2·095
MnO	·076
MgO	37·014
K_2O, Na_2O	trace.
H_2O	16·07
	100·223

In addition to the normal type of serpentine, examples of the type intermediate between the serpentines and true gabbros also occur in this region and are of considerable interest as lending support to the conjecture that some of these varieties of intrusive rocks may be modifications of the same basic magma. An excellent example of this intermediate type occurs on the north-west slope of the Breaker Hill, about the level of the 700-feet contour line, at the southern margin of the serpentine. The locality may be readily found, as it lies about a mile to the north-west of the Daljarrock limestone quarry, at a point where a branching vein of serpentine leaves the main mass (see Sheet 7). By following the stone fence from Daljarrock Wood in a north-west direction to the margin of the serpentine, the observer will find the spot without difficulty. A specimen (No. 6430) collected from this locality is described by Mr. Teall as "a dark, almost black rock, containing small irregular white patches, which are unevenly distributed through the specimen. This rock bears a close resemblance to varieties of serpentine which occur at the Lizard, and which are intermediate between true serpentines and gabbros. The white patches probably represent felspars. The microscopic examination shows that the constituents include olivine, augite, hornblende, biotite, serpentine, iron ores, and a turbid substance which probably represents felspar.

* Trans. Roy. Soc. Edin., vol. xxviii., p. 494.

"Serpentine derived from olivine, with the unaltered mineral still preserved in the cores of the meshes, is an important constituent of the rock. The augite is nearly colourless, and occurs both in the form of large irregular plates and as granulitic aggregates. The hornblende is peculiar as regards its colour and pleochroism, α, colourless, β and γ, rich but not very deep brown, and with only slight differences. Biotite is not present in any considerable quantity. It occurs as aggregates of small scales, and possesses the same colour as the hornblende.

"This rock possesses decided affinities with the hornblende-picrite from Penarfywydd in Anglesea (see 'British Petrography,' Plate vii., Fig. 5), described by Professor Bonney. It also resembles certain banded rocks which occur at the Lizard in intimate association with serpentine ('Some Coast Sections at the Lizard,' Fox and Teall, Quart. Jour. Geol. Soc., vol. xlix. (1893), p. 200). The resemblance in this case is, however, limited to mineralogical composition; both rocks contain the colourless augite and the peculiar brown hornblende, together with serpentine, olivine, and turbid alteration products after felspar. The Lizard rock is a well banded schist, whereas the Ayrshire rock is massive, with, however, a marked variation in the amount of altered felspar present in the different portions of the specimen."

A rock of a similar intermediate type was observed on the slope of Balhamie Hill at a point about 200 yards west of Balhamie Burn, where it appears as a thin vein of dark massive material in serpentine. Under the microscope, this rock (No. 6432) "shows numerous large irregular individuals of olivine only partially serpentinised in a fine-grained matrix, composed of small irregular individuals of pale brown hornblende, and serpentinous and chloritic alteration products. There are also some turbid alteration products, which may indicate the presence of a small quantity of felspar." This rock has been named by Mr. Teall hornblende-picrite.

Regarding the relations of the serpentine of the southern belt to the bedded lavas, tuffs, and associated sediments, it is clear that the boundary-line between the two series of rocks in some cases is a fault or line of movement. Such seems to be the nature of the boundary along the north side of Knockdolian Hill, where the serpentine rises to a height of about 400 feet (Fig. 107). Along the margin, and especially on the north-west part of the slope, the serpentine has been rendered schistose, fine flaser-structure being observable at certain places. Where this feature is developed the rock is traversed by calcareous veins, which in some instances have been burnt for economic purposes. Between Knockdolian and Garnaburn, north-east of Colmonell, the boundary of the serpentine is concealed by superficial deposits; but along the Prieston and Poundland Hills the junction is probably a faulted one. On the Breaker Hill a vein of schistose serpentine is traceable from the main mass into the bedded lavas.

In the river Stinchar, at the base of the south-eastern slope of Knockdolian Hill, the serpentine is in contact with black shale, which, as already stated, is believed to be on the horizon of the Middle Arenig band at Bennane Head. The junction, which appears to be an intrusive one, is visible only when the river is low. Here also the volcanic agglomerate is indurated, probably by contact with the serpentine. Though the rock cannot be traced continuously from the river to the Leffin Knowes, north of Balknowlart, at the base of the south-west slope of Knockdolian, it probably occupies the hollow at Macherwhat.

In probable underground continuity with the mass on the south side of Knockdolian, the serpentine is again seen on the left side of the river near Salachan. On the south-east side of Salachan Hill it is exposed in various quarries at the roadside near Knockdhu Bridge, associated with a mass of gabbro, which will be referred to in the sequel. At the edge of the wood, where there is a bend in the high road leading to Colmonell, schistose green serpentine is visible, and in a quarry at the roadside close to Knockdhu Bridge the rock has a red tint.

North-east of Ballantrae, between Balnowlart and Croseclays, the boundary of the serpentine, as mapped, is conjectural, for the ground is largely covered with superficial deposits, but an excellent section of the schistose variety of the rock is displayed in the Drummore Burn, to the south of Bennane Head. Reference has already been made to the fact that near the mouth of the Bennane Burn (Bennane Head), at the margin of the old sea-beach, the serpentine is intrusive in the radiolarian cherts. Along the northern margin of the area, from the shore south of Bennane Head eastwards in the direction of Boghead, the boundary is concealed, and between Boghead and Knockdaw Hill there seems to have been a certain amount of movement between the serpentine and the Arenig lavas lying to the north of it.

Northern Area.—The lithological characters of the serpentine in the northern tract resemble those met with in the southern belt. The rock at various points on the shore between Pinbain Burn and Burnfoot is associated with numerous bosses of gabbro and veins of dolerite. Its principal varieties, as exposed on this part of the coast, have been described by Professor Bonney. He states that "about Lendalfoot the serpentino has a rather conchoidal fracture, with a very compact dark olive-green ground mass, containing rather minute and not very lustrous bronzitic crystals and thin veins of chrysotile. On placing a slide beneath the microscope, we see that the structure made so familiar by the Lizard specimens (Quart. Jour. Geol. Soc., vol. xxxiii., p. 916) is at once evident, though in this specimen the black iron peroxide is less markedly aggregated in the neighbourhood of the strings of doubly refracting serpentine, and the distinction between 'strings' and doubly refracting 'mesh' is less conspicuous. Much of the iron is disseminated in extremely minute granules over the field, which, with crossed Nicols, shows fibrous serpentine extending towards the centre of

the mesh, and sometimes occupying the whole. Where these strings are more clearly defined they exhibit a rough parallelism, and the fibrous structure is at right angles to them. The serpentine is irregularly banded with chrysotile. One vein shows unusually bright colours with crossed Nicols. There are two or three grains of a rich brown mineral, probably picotite. Here and there is a little of a fibrous, very strongly dichroic green mineral, changing from light green to almost black. Altered bronzite is present in rather small grains, and a clear yellowish mineral, with very minute belonites, about ·001 inch in length, crossing nearly at right angles, so as to form a sort of prismatic reticulation."*

On the shore to the south of Carleton Port, red serpentine appears with crystals of bastite and veins of chrysotile; to the south of the fifth milestone from Ballantrae the dark green variety is met with, and near Burnfoot beautiful red and green mottled serpentine is exposed on the shore.

The following is a description by Professor Bonney of the microscopic character of two varieties of the red serpentine from this district.†

(1) "Specimen from south of Burnfoot. In general structure this resembles the other, except that the 'meshes' are often partly or wholly occupied by an imperfectly translucent ferruginous mineral of burnt-sienna colour, doubtless akin to hæmatite and the colouring matter of the rock. There is some calcite in a crack traversing the slide, mixed possibly with a little minute dolomite; it also occurs associated with a microlitic 'dust' replacing some (? pyroxenic) mineral. Bronzite is present, though in small grains, and much altered.

(2) "Specimen collected from rocks a little to the south of Carleton Port headland. This is a compact rock of an Indian-red colour, marbled or mottled with purplish or purplish-grey, in which are rather rounded grains or 'eyes' of a greenish mineral, apparently a decomposed bronzite. Under the microscope this rock is seen to be in general structure very similar to the last, but with the 'strings' a little more definitely parallel; to these also the coarser part of the ferruginous constituent is rather more restricted, though an extremely minute dust is everywhere thinly disseminated in the serpentine. There is bronzite, much altered, and a minute grain or two of picotite (?)."

When the northern belt of intrusive rocks is traced inland from the shore, numerous exposures of serpentine, having a green tint and sub-conchoidal fracture, occur on the moor to the south-east of Pinbain Hill. The schistose variety is met with near Laigh Knockclauch, in the valley of the Lendal Water. In a small stream, about 100 yards west of the ruins of Lochton Cottage, near the margin of the serpentine, a dark-green massive rock, when examined under the microscope, is found to consist "mainly of an aggregate of irregular grains of a colourless

* Quart. Jour. Geol. Soc., vol. xxxiv., p. 775.
† Quart. Jour. Geol. Soc., vol. xxxiv., p. 776.

monoclinic pyroxene. It contains also yellowish patches and veins of serpentine." This rock has been termed Pyroxenite by Mr. Teall (Pyroxenolite of Lacroix). At the extreme north-east limit of the serpentine, on the north-east slope of Byne Hill, the rock is dark-green and compact, containing a few small crystals of bastite. Under the microscope it shows "bastite, serpentine, and a few irregular grains of picotite."

With reference to the relations of the northern belt of serpentine, it seems clear that the south-east boundary, extending from Carleton Hill to Lochton, south of Byne Hill, has been a line of movement, as the rocks along the junction show marked flaser-structure. The flaser-epidote rocks at the margin of the serpentine on Carleton Hill and in the Lendal Water, near Lendalfoot, have been already referred to, and highly sheared rocks likewise occur along the boundary near Loch Lochton. In like manner, on the south-eastern slope of Byne Hill, there is evidence at one place of deformation along the boundary between the serpentine and the mass of gabbro and dolerite to the north. On the shore near the mouth of Pinbain Burn, as already described (see Fig. 104), the serpentine is intrusive in the Middle Arenig black shales, and pierces the Arenig lavas and agglomerates.

Gabbro, Dolerite, Epidiorite, Diorite, Granite.

A remarkable feature of the intrusive series is the abundance of irregular and lenticular masses of various types, chiefly basic, which occur within or at the margin of the serpentine areas, or as small isolated bosses piercing the Arenig lavas and agglomerates. Owing to their number, special reference will be generally restricted to those from which illustrative specimens have been taken for microscopic examination.

Beginning with the coarse gabbros and gabbro-pegmatites, we find in one of the small streams draining the south-east slope of Pinbain Hill, in association with the serpentine, a highly altered coarse-grained gabbro-pegmatite, composed of individual crystals measuring an inch or more across. A specimen (No. 6440) shows under the microscope "that the felspar is entirely replaced by secondary substances, of which a brown isotropic material is the most common. It occurs in small grains, granular aggregates, and as irregular patches. More or less altered crystals of pyroxene also occur." A similar change is observable in a vein of coarse gabbro in serpentine at Lendalfoot. The vein is about three-quarters of an inch thick, and is mainly composed of a nearly white compact substance. Under the microscope (No. 6439), "the white substance cannot be definitely referred to any distinct mineral. It appears brown in thin section, is without action on polarised light, and may possibly be garnet. A brown substance is frequently found as an alteration of felspar in the Lizard gabbros, but this is doubly refractive." Another specimen taken from an exposure, a little north of Lendalfoot (No. 6441), shows under the microscope that the felspars are

entirely replaced by ill-defined saussuritic substances, while the dillage is partly preserved and partly uralitised. These coarse gabbros with their giant crystals, and with no chilled margins, may be the pegmatites of the rock which gave rise to the serpentine.

Among the best examples of coarse gabbros are those found on the beach between Lendalfoot and the mouth of Pinbain Burn, which have been described by Professor Bonney and Professor Heddle. On the sandy beach, about 450 yards south of the mouth of Pinbain Burn, a vein of coarse gabbro, that runs in a westerly direction, occurs in the serpentine and traverses an older gabbro composed mainly of diallage. The junction between the serpentine and the westerly vein of gabbro is visible. The former rock is seen adhering to the edge of the latter, and small inclusions of serpentine occurs in the gabbro. A specimen (No. 7806) taken from the northern edge of this vein, where the rock is fine-grained and schistose, shows under the microscope "that it has been subjected to a considerable amount of dynamic action and that the marginal portion was originally a fine-grained rock, similar to the bands of fine-grained granulitic gabbro near Millenderdale," to be referred to presently. The following description by Professor Bonney applies evidently to this locality south of Pinbain Burn, where he recognised gabbros of two ages:*

"Rising conspicuously above the serpentine and the sand are two dykes of a hard whitish rock, spotted with brown. A short examination shows this to be a gabbro of plagioclase and diallage, in which, as at the Lizard, the former mineral has been converted into a kind of saussurite. It always forms the major part, and sometimes almost the whole of the rock. As it resists the weather better than the diallage, the rock has often a curious "pock-marked" aspect. Close at hand is a most remarkable rock, best seen near the southern dyke of gabbro, though a little of it also occurs near the other. This rock consists almost wholly of coarsely crystallised sub-metallic diallage, the crystals being often two or three inches long. It breaks into serpentine in irregular branching veins, which die away in mere threads (remaining rather coarse to the last, like the gabbro at the Lizard); in places it has almost shattered the serpentine, and includes fragments of it. Its weathered surface, as might be expected, is extremely rough, the diallage crystals projecting. The thicker parts of the mass form little skerries. Here the rock may be four or five feet thick, but generally it is in veins not more than a foot across. Careful examination left not the slightest doubt on my mind that this is a true intrusive rock, and has not been formed by segregation or otherwise.

"I have examined microscopically each of the above rocks. In the former, the saussuritic mineral is partly translucent, but for the most part is rendered opaque by a fine earthy dust with

* Quart. Jour. Geol. Soc., vol. xxxiv. (1878), p. 778.

a somewhat fibrous arrangement. With crossed Nicols the field is generally dark, but exhibits occasional specks and streaks of brighter colours and indistinct traces of aggregate polarisation. In one or two parts, however, some very characteristic plagioclase felspar still remains (very transparent and free from all enclosures, except some minute dark acicular microliths), thus indicating the origin of the saussuritic constituent.

"The other constituent of the rock exists in three forms—(a) Crystalline grains of diallage (and in one or two cases of normal augite) comparatively little altered; (b) wholly or partly replacing diallage, green-coloured, strongly dichroic, exhibiting occasionally very characteristic hornblende cleavage; (c) a transparent, nearly colourless, and non-dichroic, rather fibrous mineral, which sometimes is associated with either of the above, sometimes occurs alone. Part of this exhibits brilliant colours with crossed Nicols; part changes from a light bluish white to a blue-black like some fibrous serpentines; the former mineral is probably actinolite, the latter may be only a variety of serpentine. This rock thus appears to have been a coarsely crystalline gabbro, which, perhaps, contained a little olivine.

"The second rock is practically a mass of diallage crystals. Some of these are very fairly preserved, others are traversed by cracks with dusty borders, showing incipient decomposition; while others are green-coloured and dichroic, indicating a change towards uralite. Others, again, are full of microliths, which are bright-coloured between crossed Nicols, while the main part of the crystal is dull or dark."

The following description of coarse gabbro by Professor Heddle applies to one of the localities on the shore north of Lendalfoot.*

"The specimens examined were from a low spit which protrudes far seawards about mid-tide level. This consists for the most part of the diallage in large platy and intermatted crystals; these lie embedded in a granular massive hydrated saussurite, the rock here being also of singularly simple constitution, with no accessories.

"The diallage here is an excellent type of this variety of augite, broad cleavage foliations and even crystal faces flash with a splendent lustre, but with a uniformity which is frequently broken by a singular reticulated or arborescent appearance, the interrupting duller structure having the ordinary non-lustrous appearance of the stone."

"The pseudo-metallic semi-nacreous flash, brought out in certain positions by reflected light, appears to arise from an internal reflection from flat fissures or broad cleavages. Rough crystals of half the size of the palm of the hand may here be obtained.

* Trans. Roy. Soc. Edin., vol. xxviii., p. 464.

"The colour is olive green; the specific gravity is 3·251. 1·3 grammes yielded—

Silica, - - -	·66		
From alumina, -	·013		
	·673	=	51·769
Alumina, - - -			2·1
Ferrous oxide, -			2·955
Manganous oxide, -			·307
Lime, - - -			22·098
Magnesia, - -			18·461
Potash, - - -			·628
Soda, - - -			·579
Water, - - -			1·085
			99·982

Insoluble silica, 3·863. Impurity unknown."

Within the serpentine area near Burnfoot, and about a mile south of Lendalfoot, an interesting type of gabbro shows partial conversion into aluminous serpentine. Regarding a specimen of this type (No. 6442) Mr. Teall notes that "the whole mass has been converted into a soft translucent substance which can be cut with a knife. The darker and lighter portions of this substance probably mark the positions of the original felspar and diallage, but no trace of these minerals remains. Under the microscope the rock shows a more or less structureless mass of indistinct flecks and scales. I have no doubt that this is an aluminous serpentine (pseudophite) similar to that which has been described as occurring near Kynance at the Lizard, where it also arises as an alteration product from a coarse-grained gabbro." Another specimen of altered gabbro from the same place (No. 6443) shows "altered felspar, green and brownish-green hornblende, a little unaltered augite, surrounded by green hornblende, biotite (scarce), and iron-ores."

No less interesting is the evidence of the replacement of the pyroxene by hornblende in the gabbro masses. One example occurs on the south-east side of Salachan Hill, in the valley of the Stinchar, about a mile to the south-west of Craigneil Castle, where uralitic gabbro is found in association with the serpentine, as already indicated (p. 471). Under the microscope, this coarse-grained granitoid rock (No. 6447) is found to be composed "of altered plagioclase and pyroxene, largely replaced by hornblende. The secondary hornblende has often been developed as minute pale green needles of actinolite, which do not lie with their axes parallel."

At the base of the south-east slope of Balhamie Hill, a quarry in a field near Deafstone Farm, about 700 yards N.N.W. of Colmonell Parish Church, affords an excellent exposure of a peculiar type of gabbro-like rock, which occasionally occurs within the serpentine area. The serpentine is seen a little to

the north of the quarry, but its relations to this rock are not visible. A typical specimen (No. 6450) was examined by Mr. Teall, on which he makes the following note: "The rock is composed of large and more or less irregular black and white patches. The black patches are formed of hornblende, and the white of felspar; both minerals occurring rather as aggregates than as individuals, although cleavage faces an inch across may sometimes be observed in the hornblende. Under the microscope are seen plagioclase in large plates, and more or less granular aggregates belonging to the andesine-oligoclase series, and brown compact hornblende also occurring in large irregular individuals and as aggregates. Apatite and iron-ores occur as accessories."

Proceeding now to the consideration of those phases of the gabbro which show "flaser" and "augen" structure, we may observe that these types are best seen in the basic masses in the southern belt of serpentine between Balhamie Hill and Millenderdale. Perhaps the finest examples of the foliated type in the Ballantrae region are to be found on the moor, about one third of a mile to the east of Millenderdale Farmhouse. Here the foliated igneous rocks form a series of rocky knolls or bosses, traceable at intervals over half a mile of ground, until they are covered unconformably on the north side by the Benan Conglomerate and associated strata. Where the foliation planes are best developed, at the south-east margin of these bosses, their general dip is towards the W.N.W. and N.W. at angles varying from 50°–55°. Special reference may be made to the section exposed on a rocky knoll, 600 yards east of Millenderdale, on the north side of a stone-fence that runs due east from that farmhouse. Here bands of coarse gabbro alternate with fine-grained granulitic gabbro, both having a common foliation, the planes of which dip to the W.N.W. Both types are traversed by irregular veins or dykes of fine-grained igneous rock, which, though they cut the foliated masses, are not themselves, schistose. Specimens of these three varieties were here taken for microscopic examination which are thus described by Mr. Teall. The first (No. 7793) is a coarse-grained, foliated, saussuritic gabbro. "Its principal constituents are brown hornblende, a pale or colourless pyroxene and plagioclase (altered). These three constituents occur either in large individuals or in the granulitic condition. The large pyroxenes are more or less inter-grown with brown hornblende, and frequently have on their margins a granulitic aggregate of hornblende and pyroxene. Iron ores are locally abundant in the thin section, and bear the same relation to the other constituents as they do in the rocks of Druim-na-Eidhne (Skye), that is, they are often allotriomorphic with respect to these constituents." The second specimen (No. 7791), exhibits a junction between the coarse and fine types of foliated gabbro. "The coarse rock is a saussuritic gabbro in which the large pyroxenes are more or less replaced by brown hornblende. The fine-grained rock is a granulitic aggregate of brown horn-

blende, malacolite and felspar (altered). These granulitic rocks appear to me to be comparable to the granulitic gabbros of Druim-na-Eidhne." Other two examples of the fine-grained types (7792 and 7794) resemble the fine-grained portion of 7791; one of them being exceptionally rich in brown hornblende. Mr. Teall considers that these fine-grained rocks may be conveniently referred to as basic granulites. The remaining specimen (No. 7795) was taken from a dyke that cuts both gabbros and granulites. Under the microscope it shows "phenocrysts of turbid plagioclase (indeterminable), in a granulitic matrix of turbid felspar, unaltered malacolite and chlorite. The groundmass of this rock is similar in structure to that of the granulites and the malacolite is of the same character. There is, however, no brown hornblende.

Again, on the north-west face of the Breaker Hill, about a mile S.S.E. of Millenderdale, at the margin of the serpentine, another example of the foliated type is met with. When examined under the microscope, the section (No. 6444) shows that "some folia are composed almost entirely of a colourless granular pyroxene; others of decomposition products after felspar. The rock is too much altered for precise determination, but it is probably a foliated phase of the gabbro."

The moor between Poundland and Knockdaw Hill, where the veins of massive picotite occur, near the source of the Poundland Burn, presents a coarse-grained somewhat foliated rock of the gabbro type, which, when examined microscopically (No. 6448), shows "felspar mostly destroyed by alteration, pale-coloured pyroxene in large patches, and granulitic aggregates; biotite also in large plates, and granulitic aggregates and iron-ores."

The serpentine area between Poundland Moor and Balhamie Hill, includes a type of fine-grained banded rocks of granulitic structure, which have probably been subjected to dynamic metamorphism, and which contain an interesting assemblage of minerals. One example of this series forms a small boss protruding through the turf, close to the edge of a drained lochan, at the southern margin of the serpentine area, about a mile north-east of Garnaburn Farmhouse. Microscopic examination shows that this banded granulitic rock (No. 6494, Plate XXII., Fig. 1) is "composed of malacolite, brown hornblende, and felspar. The specimen is traversed by a well-marked grey band, in which malacolite occurs to the exclusion of the serpentine, and in which iron-ore is fairly abundant." Another instance is met with on Balhamie Hill, at a point about half a mile due west of the cairn on the hill-top, where the granulitic rock appears as an isolated knoll near a sheep-fold. A specimen taken from this exposure shows, under the microscope (No. 6495, Plate XX, Fig. 2), that the rock is "essentially composed of granulitic felspar and brown hornblende, together with a small quantity of reddish-brown biotite. The grains are not uniformly scattered through the slide, but occur in aggregates. In some places the felspar

aggregates appear to replace more or less idiomorphic felspars; in others the aggregates of both felspar and hornblende form streaks or folia. It is highly probable that the granulitic structure is wholly secondary." A third example forms a small boss in the midst of an alluvial flat a third of a mile E.N.E. of the cairn at Balhamie Hill-top, and a third of a mile south-east of Lochhead. From a microscopic section (No. 6497) it appears that the rock is "too fine in grain for precise description, but apparently it is a foliated rock, composed essentially of small grains of brown hornblende and altered felspar. It is a rock similar to the one previously described (No. 6495), in which shearing has affected the entire mass."

In the northern belt of serpentine, on the north-west slope of Carleton Hill, near Lendalfoot, a mass of epidiorite near the margin of the serpentine, is associated with a small development of hornblende-schist. A specimen of the epidiorite, when examined microscopically (No. 6502), displays "irregular patches of very pale green hornblende, and more or less altered felspars, which often show lath-shaped outlines penetrating the hornblende; the hornblende is probably secondary after augite; iron-ores are scarce." A section (No. 6503) of the hornblende-schist, which forms part of the same mass, shows that the rock is composed of "green hornblende and felspar, with iron-ores and chlorite as accessories." Another example (7802) of fine-grained hornblende-schist with much epidote, occurs at the margin of the northern belt of serpentine, in a burn about a quarter of a mile west of Laigh Knockclauch. A narrow lenticle of garnetiferous hornblende-schist is to be found within the serpentine area and about thirty yards from its margin on the hill slope, 600 yards north-west from Laigh Knockclauch, which has already been described in connection with the flaser-rocks along the southern margin of the serpentine area between Lendalfoot and Lochton (p. 458). The planes of schistosity in this lenticle are roughly parallel to the boundary of the serpentine, and towards its western limit it shows evidence of having been subjected to marked dynamic action.

In addition to these examples which show more or less trace of foliation probably due to dynamic action, some granulitic rocks, exposed in small isolated masses within the serpentine area, suggest the probability of their present structures being due to contact metamorphism. They are found on the Littleton Hill, the western termination of Balhamie Hill, near the edge of the cultivated ground, and about half a mile north of Bougang Farmhouse. Three sections have been prepared from specimens taken from these bosses, viz.: Nos. 5927, 5928, and 6496. The first (5927, Plate XX, Fig. 1) shows "phenocrysts of basic plagioclase in a granular aggregate of brown hornblende and felspar, reddish-brown mica being also present." The second is composed of "a granulitic aggregate of brown hornblende and felspar, with minute specks of iron-ore." The third displays "a few phenocrysts of felspar in a ground-mass of brown hornblende

and more or less lath-shaped felspar, with a few specks of iron-ore." The relations of these granulitic rocks to the serpentine are here also concealed from view. All that we certainly know is that the rocks lie within the serpentine area. Their origin is a matter of doubt. If they represent an altered phase of the porphyritic diabase-lavas, then the matrix must have been entirely recrystallised.

Reference may now be made to certain lenticular masses and veins of dolerite, which at various places present chilled margins along their lines of contact with the serpentine. Frequently they have a sinuous course, and are very irregular in their mode of occurrence, differing in this respect from the basalt dykes of Tertiary age. Professor Bonney has already called attention to the existence of rocks of this type near Lendalfoot hamlet, suggesting that they are veins rather than dykes. He states that "in the thicker parts they resemble dolerites, mottled, dull, white and dark-grey (sometimes like a fine variety of the Corstorphine rock), and they appear to pass into thin veins (less than a foot thick) of a compact pinkish-grey rock with dull, green spots." He adds that the microscopic examination confirmed his view of the igneous character of these rocks, for "the coarser varieties consist mainly of felspar (or rather of what was once felspar, probably plagioclase, but is now an aggregate of earthy dust and bright-coloured irregular microliths) and well-preserved augite, of a serpentinous mineral, and of decomposed ilmenite. The finer variety is so completely decomposed as to show little of its original constitution."*

During the recent revision by the Geological Survey, three specimens were taken from one of these intrusive dykes on the shore 300 yards north from the hamlet of Lendalfoot opposite the Sailor's Monument (Plate XIV); the first from the chilled margin in visible contact with the serpentine, the second a little further inwards, and the third from the centre of the mass. This intrusive mass, which runs roughly parallel to the shore, contains small inclusions of serpentine and the latter rock is likewise seen adhering to the walls of the dyke. The first (No. 6451) is a dense compact grey rock that shows a few phenocrysts of plagioclase in an extremely fine-grained matrix, the constituents of which cannot be satisfactorily determined, the second (No. 6452) is a medium-grained, dark, massive rock, which under the microscope shows "augite, lath-shaped plagioclase, and iron-ores, with chlorite and epidote as secondary accessories. Biotite occurs generally in association with the iron-ores as a primary accessory"; the third (No. 6453) is a moderately coarse-grained dark massive rock, "which has the same constituents as the preceding, with this exception, that biotite is not present as an accessory."

At Lendalfoot a porphyritic dolerite likewise occurs as intrusive veins in the serpentine. A slide of this type (No. 6454)

* Quar. Jour. Geol. Soc., vol. xxxiv., p. 788.

Junction of Dolerite dyke (light coloured mass) with Serpentine (darker mass), stack on shore 300 yards north of Lendalfoot.

displays "phenocrysts of basic plagioclase, often measuring more than a quarter of an inch across, set in a ground mass of augite, lath-shaped plagioclase, and iron-ores, with chlorite and epidote as secondary accessories." Similar porphyritic dolerite with chilled margins occur at the edge of the serpentine area, on the south-west side of Knockdaw Hill.

These intrusive dolerites are well developed in the neighbourhood of Garna Burn, about a mile north-east of the village of Colmonell, where they form rocky knolls protruding through the serpentine on the west side of the valley. The junctions with the serpentine are visible about half a mile up the stream from Garnaburn Farmhouse, at the south-eastern limit of the alluvial flat below Boghead. A section cut from a knoll, about 200 yards south-east of Boghead Cottage (No. 5926), shows "a few large grains of olivine, traversed by veins of magnetite and presenting a turbid appearance, in consequence of the presence of minute specks, lath-shaped plagioclase, pale-brown augite, brown hornblende, and iron-ores." The rock has been named by Mr. Teall a porphyritic hornblende-olivine-dolerite. Similar intrusive junctions between the dolerites and serpentine occur on the east side of Garna Burn, on the moor, about three-quarters of a mile due north of the farmhouse of that name.

Again, at the base of the northern slope of Knockdolian Hill, several lenticular masses of basic rock protrude through the serpentine; one of these, named on the six-inch map "Duniewick," has a chilled margin with the serpentine, the latter adhering to it in patches. The strip of intrusive rock which forms Balnowlart Knowes, about a mile and a half north-east of Ballantrae, and is bounded on the north by serpentine, on the south by volcanic agglomerate, is composed of dolerite, containing augite, plagioclase, and iron-ores, with chlorite as a secondary product. In like manner the rock at the Castle of Ballantrae, which pierces the agglomerate of Mains Hill, is a dolerite (No. 6460) with traces of ophitic structure, and containing augite, altered plagioclase in broad lath-shaped sections, iron-ores, and chlorite. The rock at Ballantrae Harbour, the relations of which are uncertain, is a dolerite which shows under the microscope (No. 6461) plagioclase, augite, and iron-ores, with chlorite and other decomposition products.

The mass of basic and acid intrusive rocks which extend from the Byne Hill to the Grey Hill, present certain interesting petrographical features arising from the marked variation of the rock-types. This mass forms a narrow strip, bounded on the south-east by serpentine and on the north side partly by the Benan Conglomerate, partly by the Arenig lavas, and partly by serpentine. The main portion of the area is composed of gabbro, hornblende-gabbro, and dolerite; while the Byne Hill and Grey Hill display two small patches of quartz-diorite and granite, which to all appearance pass gradually into the more basic varieties. Where the basic rocks are in contact with the serpentine, they are more fine-grained than towards the centre

of the mass. Some of the microscopic sections prepared from specimens taken from the margin on the east and south-east sides of Byne Hill show brecciation or cataclastic structures, due to movement between the basic rocks and the serpentine.

In order to show the variation in the rock types and the character of the rocks at the margin, specimens were collected from the east and south-east slopes of Byne Hill, which have been examined by Mr. Teall, who furnished notes on the respective specimens and microscopic sections. Several were taken from the margin of the basic mass, nearly due east of the cairn on the hill-top; the rest were collected from the south-east slope, along a line extending from the junction with the serpentine in a north-west direction towards the cairn on the hill-top.

The observations of Mr. Teall may thus be briefly summarised. On the east side of Byne Hill, the basic rock in contact with the serpentine (No. 6465) is compact, and shows under the microscope "a confused crypto–or micro-crystalline aggregate of indeterminable minerals. Here and there granular aggregates of pyroxene may be recognised, and small grains of iron-ore are scattered through the slide. The original character of this rock appears to have been destroyed both by alteration of the constituents and by movement." Another specimen (No. 7786) also from the margin of the basic mass in contact with serpentine is "a compact brownish rock, showing decided traces of a porphyritic structure when examined with a lens. Under the microscope, the phenocrysts are found to be either felspars or pseudomorphs after idiomorphic augite. The pseudomorphs after augite are formed either wholly or partially of brown hornblende similar to that which occurs in the rocks of Littleton Hill (No. 5927). The ground-mass is very fine in grain. Examined with a high power, it is seen to be an aggregate of brown hornblende and felspar. It resembles the ground-mass of the rocks from Littleton Hill in composition but the structure is much finer."

Westwards from its margin, for a distance of about 70 yards, the basic rock varies from hornblende-olivine-gabbro (No. 6470), with "large ophitic individuals of nearly colourless augite, olivine, labradorite, with brown hornblende as an accessory constituent," to hornblende-gabbro. The latter rock (No. 6475) contains hornblende, both brown and uralitic, altered felspar, iron-ores, little or no pyroxene and a little biotite. At a point about 76 yards from the edge of the intrusive mass, the eruptive rock becomes richer in felspar. About 86 yards from the margin it merges into a quartz-biotite-diorite, and still nearer the top of Byne Hill into biotite-granite, with oligoclase, orthoclase, quartz and biotite.

Similar evidence is obtained from the southern slope of the Grey Hill, where a fringe of basic rocks (dolerite and gabbro) surrounds the core of granite.

Though the evidence in the field shows that the passage from the hornblende-gabbro to quartz-biotite-diorite and biotite

granite is tolerably abrupt, yet no indication of a chilled margin or intrusive junction is observable. It is probable, however, that by a process of differentiation the biotite granite may be a slightly later product of the same magma that gave rise to the basic rocks.

On referring to the Geological Map (Sheet 7) it will be seen that the various plutonic rocks have been injected mainly along the bedding-planes of the volcanic series and overlying sediments. Fortunately there is definite evidence regarding the date of these intrusions, for they are clearly older than the formation of the Kirkland and Benan Conglomerates, which are mainly made up of their detritus and rest unconformably on the volcanic platform. It is interesting to observe that the evidence, though imperfect, points to the conclusion that the total thickness of conformable sediments under which the intrusive rocks were injected was not great, and yet the injections include coarsely crystalline rocks such as gabbro and granite.

CHAPTER XXI.

THE GIRVAN DISTRICT—*continued.*

LLANDEILO-CARADOC SEDIMENTARY (GIRVAN) SERIES.

AFTER the completion of the volcanic episode in Lower Silurian time, and the deposition of the Arenig cherts and overlying sediments, these various accumulations were elevated and exposed to denudation. During this process the cover of conformably overlying sediments was removed, and the lavas, agglomerates, and accompanying plutonic rocks were laid bare. The detritus of these older rocks furnished the materials of the conglomerates (Kirkland and Benan) at the base of the Girvan series, the green matrix of the conglomerate being made up of triturated igneous materials, and the pebbles being composed of Arenig chert, black shale, lavas, and tuffs, together with serpentine, gabbro, dolerite, and even the granite of Byne Hill. These conglomerates, which are associated with the Stinchar Limestone, rest unconformably everywhere to the north of the Stinchar valley on all rocks older than themselves, sometimes on the serpentine and gabbro. Further, relics of the Stinchar Limestone group with its characteristic fossils occur as small outliers on the plateau of intrusive igneous rocks at Bougang and near Knockdolian Barns. Indeed, from the manner in which different members of the Benan Conglomerate and Stinchar Limestone group overlap each other, and successively rest on the volcanic plateau, it appears that the latter must have been subjected to unequal movement and subsidence towards the close of Llandeilo time.

In the historical account of Professor Lapworth's researches in the Girvan area (Chap, II), a description has been given of the order of succession of the fossiliferous rocks of the Girvan series which he established. During the recent examination of that region by the Geological Survey, his views regarding the physical relations of the beds and the sequence of the groups have been confirmed, save in some minor points. To his paper on "The Girvan Succession," of which ample use has been made in the preparation of this description, the reader is referred for more minute details than are here given. In the sequel we adopt the general classification which he propounded.

The Barr Series.

The members of this series are typically developed on the north side of the valley of the Stinchar, near the village of Barr,

where the characters of the various sub-divisions and their relations to each other are displayed in numerous natural sections. Here they present the following succession in descending order:

	7. Benan conglomerate.
Stinchar Limestone Group.	6. Green mudstones and shales with graptolites.
	5. Compact limestones, sparingly fossiliferous.
	4. Nodular limestones with frequent partings of shales, highly fossiliferous (*Maclurea*-beds).
	3. Impure calcareous flags with *Orthis confinis*.
	2. Purple sandstoues and grits.
	1. Purple conglomerate (Kirkland).

The dominant feature of this series is the massive conglomerate of Benan, so remarkable in its lithological characters and so strikingly developed on the elevated ridge forming the Benan, Kirkland, and Auchensoul Hills, north of the Stinchar valley. The peculiar dark-green matrix, derived from the disintegration of the basic igneous rocks, which, when exposed to atmospheric agencies along the banks of the stream, decomposes readily and frequently crumbles away under the touch of the hammer, and further, the varied assemblage of well-rounded boulders from the Arenig volcanic plateau, are features that cannot fail to impress the geologist. From the Benan Hill to the terraced slopes of the Milljoan and Milton Hills this remarkable conglomerate can be traced along the strike for a distance of six miles, while from the village of Barr it stretches northwards to the sources of the Water of Assel and Penwhapple Burn. It reappears in many other remarkable sections, as will be shown in the sequel, but wherever it occurs its peculiar characters are readily recognised. The section chosen by Professor Lapworth to illustrate the sequence of the Barr series —that of the Benan Burn—is by far the best in the whole Girvan area (Fig. 111).

Benan Burn.—This stream, which drains the southern slopes of the Benan Hill and joins the Stinchar River about $2\frac{1}{2}$ miles to the south-west of the village of Barr, displays each subdivision of the series, and furnishes excellent opportunities for studying the zones in detail (Fig. 111). Ascending the burn from the alluvial terraces of the Stinchar, the observer, after traversing for a short distance a deposit of boulder clay, reaches the lowest member—the Kirkland Conglomerate. No great thickness of this band is here visible. It is better developed on the adjacent slopes of Craigbickerae Hill, to the south-west. The matrix of this conglomerate is usually of a purple colour, differing in this respect from that of the Benan band, which is green, and its texture is usually also much harder. It is likewise traversed by innumerable veins and strings of calcite. But as regards the constituents of the matrix, and the characters of the included pebbles, the conglomerate of Kirkland resembles that of Benan. It includes representatives of the various types of

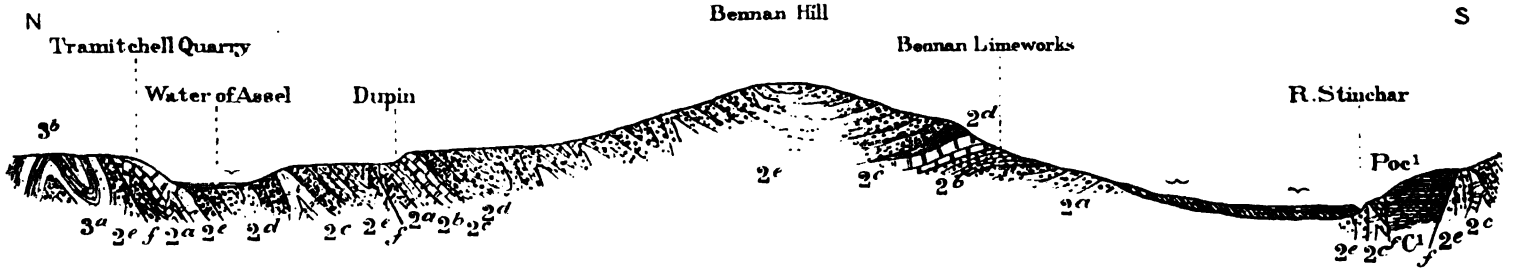


FIG. 111.—Generalised Section across Benan Hill from Tramitchell Limestone Quarry to River Stinchar. (Length, two miles.)

2a. Kirkland conglomerate. 2b. *Orthis confinis*-beds. 2c. Stinchar limestone. 2d. Graptolitic mudstones. 2e. Benan conglomerate. 3a. Balclatchie beds. 3b. Ardwell group. C1. Lower Old Red Sandstone. Poc1. Andesitic lavas of Lower Old Red Sandstone age. f. Faults. ~~ Boulder Clay. ~~ Alluvium.

Arenig lava, together with blocks of gabbro, dolerite, granite, black shale, radiolarian chert, and sandy greywacke, all of which can be identified as having been derived from the Arenig volcanic plateau and its overlying cover of sedimentary material.

The Kirkland conglomerate (2a), which dips north-westwards, is immediately succeeded by purple sandstones and grits, with partings of sandy shales forming a transitional zone between the conglomerate below and the overlying calcareous flagstones (2b). The latter zone (*Orthis confinis* flags) is one of the important fossiliferous horizons in the Barr series, and forms the lowest sub-division of the Stinchar Limestone group. These impure calcareous flagstones, owing to the irregular distribution of the calcareous matter in them, graduate into calcareous sandstones, and often contain nodules of limestone, which, when dissolved out, give rise to a honey-combed surface. Weathering with a brown or purple colour, they form a striking contrast to the nodular bands of white limestone in the overlying zone. The included fossils are almost wholly brachiopoda, and the most abundant species is *Orthis confinis* (Salter), with which are associated *Orthis alternata* (Salter), *Strophomena grandis* (Salter), &c. Dipping towards the north-west, at an angle of 25°, the *Orthis confinis* flags are immediately followed by the prominent zones of the Stinchar Limestone (2c). The lower sub-division is composed of nodular limestone, with numerous partings of shale, which, in several sections, are highly fossiliferous, yielding the characteristic form *Maclurea Logani*, with *Tetradium Peachi* and other organisms. The upper member consists of flaggy compact limestones, which are sparingly fossiliferous, though here charged with *Saccamina* and the peculiar *Girvanella*, the latter being so abundant as to constitute a prominent constituent of the rock. These limestones are admirably seen at the fork of the Benan Burn and in the branching streams, as well as in the limestone quarry where the streams unite. Though the characters of the bands may here be studied, yet the exposures are not so suitable for obtaining fossils as at Minuntion Quarry, and other places, where the rocks have been extensively worked (Fig. 111).

At the head of the Benan Burn, four rivulets unite to form the main stream, which furnish excellent sections of the two highest members of the series. The compact limestones above the fork dip to the north-west at 37° underneath a band of greenish, hard and nodular mudstones (2d). Though finely laminated, they weather in a concretionary form, break under the hammer with an irregular fracture, and likewise effervesce freely with acid. They have yielded a few graptolites and brachiopoda, but only after prolonged search. The best exposure is in the west branch of the Benan Burn, to the west of the limestone quarry, where the following assemblage of fossils was obtained by the Survey:

Glossograptus Hincksi (Hopk.)
Diplograptus rugosus (Emm.)
,, *euglyphus* (Lapw.)
Didymograptus sp.
Dicranograptus sp.
Dicellograptus sp.
Climacograptus Schärenbergi (Lapw.)
Climacograptus bicornis (Hall.)
Turrilepas sp.
Lingula ovata (M'Coy.)
,, *Ramsayi* (Salt.)
Siphonotreta micula (M'Coy.)
,, *scotica* (Dav.)

Professor Lapworth records the forms given in the annexed list from the same locality:

Clathrograptus cuneiformis (Lapw.)
Didymograptus superstes (Lapw.)
Glossograptus Hincksi (Hopk.)
Cryptograptus tricornis (Carr.)
Diplograptus rugosus (Emm.)
Siphonotreta micula (M,Coy.)
Acrotreta Nicholsoni (Dav.)

The green mudstones are overlain by the Benan Conglomerate (2e), which forms numerous small escarpments on the slopes of the Benan Hill, and dips north-westwards at an angle of 40°, which decreases to about 15° further up the hill.

Sections along the line of outcrop of the Stinchar Limestone group on the north side of the valley of the Stinchar, afford clear proof of the same succession of strata. By means of natural exposures and quarries, the limestone can be traced more or less continuously for a distance of three miles from Auchensoul Burn to Minuntion. Along this line the strata dip persistently to the north-west, as in Benan Burn.

In the Kirkland Burn, the section across the higher beds is not quite continuous, for it is truncated by small faults, but the Benan Conglomerate, graptolite shales, and limestone occupy their relative positions. From the horizon of the limestone a nearly continuous sequence may be traced downwards to the Kirkland Conglomerate.

In the neighbourhood of Auchensoul, various exposures of the fossiliferous zones are to be found, (1) on the slopes of Kirkdominae Hill, (2) in Kirkdominae Burn, (3) in the Auchensoul Burn. At some of these places the beds are much disturbed and traversed by faults, which affect the continuous sequence, but not the relative position of the strata. The fossiliferous zones of the Stinchar Limestone are visible in several old quarries on Kirkdominae Hill, where *Nidulites favus* (Salt.), *Lingulella Davisi ?* (Salt.), *Cleidophorus* sp. were collected by the Geological Survey. From the thin seams of calcareous shales, interleaved in the limestones at this locality, Professor Lapworth records *Leptæna sericea*, *Orthis caligramma*, *O. biforata*, *Turrilepas* sp., *Cythere aldensis*, *Asaphus*, *Encrinurus;* while Mrs. Gray has obtained *Cythere* sp., *Dindymene*.

In the prolongation of this series from the Benan Burn south-west to Minuntion, similar evidence may be obtained in support of the general sequence of the beds, while, at the same time, certain data present themselves, suggestive of a gradual overlap of the Benan conglomerate on to the flaggy limestones. Indeed, indications of this overlap make their appearance not far to the

west of the coomb-shaped hollow at the head of the Benan Burn. For as the upper boundary of the limestone and the lower limit of the Benan Conglomerate are followed along their lines of outcrop to the south-west, they gradually approach each other, though their actual contact is not visible, the intervening zone of graptolitic mudstones gradually disappearing from view. Professor Lapworth has called attention to similar phenomena to the west of the Auchlewan Burn, in an old quarry, where the junction between the conglomerate and the limestone is visible, which he thus describes:

"The flaggy and compact limestones dip into the hill at their normal inclination, and are irregularly surmounted by a solid mass of conglomerate dipping in the same direction, but at a slightly inferior angle. The line of contact is most irregular. The limestone has all the appearance of having been greatly eroded previous to the deposition of the conglomerate. The regular beds of limestone strike abruptly at the lower portions of the pudding-stone, and patches of the former are found adhering irregularly to the weathered basal beds of the latter. The conglomerate itself is almost destitute of anything like bedding, but some of the natural planes of deposition are shown by the linear arrangement of bands of small pebbles. In the lowest beds a few fragments of limestone are visible of the general size of marbles. The appearances seen are difficult to explain on the hypothesis of a fault, owing to the presence of patches of limestone in the conglomerate; but if they are actually due to an unconformability, we have to suppose that within the insignificant distance of about 200 yards the entire thickness of the *Didymograptus* shales must have been eroded previous to the deposition of the basal beds of the Benan Conglomerate, and in addition some slight thickness of the compact limestone itself."* Professor Lapworth, however, is of opinion that this conjunction of the beds may be ascribed partly to the effect of a fault and partly to certain peculiarities of the basal beds of the conglomerate. Similar phenomena are observable in certain exposures in the valley of the Water of Assel, to be referred to presently.

In the burn of Auchlewan, and on the adjacent slope to the east, the flaggy limestones and *Orthis confinis* flags are visible; the fossiliferous limestones are likewise seen in the deserted quarries north-west of the farmhouse of that name. By means of occasional exposures they can be traced in a south-west direction to the banks of the Stinchar at Minuntion.

Minuntion Quarry.—The section in this quarry, where the rock was formerly excavated for local economic purposes, is of special interest, on account of the excellent exposure of the *Orthis confinis* flags and the overlying limestones of the *Maclurea* zone. The characteristic brachiopoda of the former sub-division here occur in profusion, though the species are few in number.

* "The Girvan Succession." Quart. Jour. Geol. Soc., vol. xxxviii., p. 562.

The limestones are also highly fossiliferous. The fossils given in the subjoined list were here obtained from the limestone by the Geological Survey:

Serpulites longissimus (Murch.)
Crinoids.
Illœnus (Bumastus) Bowmani (Salt.)
Phacops (Acaste) Brongniarti (Portl.)
Remopleurides laterispinifer (Portl.)
,, *Colbii* (Portl.)
Leptæna sericea (Sow.)
,, *(Plectambonites) quinquecostata* (M'Coy.)
,, ,, *transversalis* (Wahl.)
Orthis calligramma (Dalm.)
,, *confinis* (Salt.)
Rhynchonella balcletchiensis (Dav.)
Siphonotreta scotica (Dav.)
Strophomena expansa (Sow.)
Pleurorhynchus (Conocardium) sp.
Bellerophon sp.
Holopea sp.
Maclurea Logani (Salt.)
,, *M'Coyi* (Salt.)
Metoptoma (Tryblidium) sp.
Ophileta (Maclurea) macromphala (M'Coy.)
Murchisonia gracilis (Hall.)
,, *bicincta* ? (Hall.)
,, *vitellia* (Bill.)
Pleurotomaria qualteriata (Schl.)
Rhaphistoma (Pleurotomaria) lenticularis (Sow.)
Trochus sp.
Cyrtoceras inæquiseptum (Portl.)

From the underlying calcareous flags, the Survey has collected *Orthis confinis* (Salt.), *O. flabellulum* (Sow.), *O. calligramma* (Dalm.), *Strophomena expansa* (Sow.)

In addition to these fossils from the limestone, Mrs. Gray records the following:

Lingula granulata (Phil.)
,, *Ramsayi* (Salt.)
Rhynchonella nasuta (M'Coy.)
Asaphus gigas (De Kay.)
Cheirurus bimucronatus (Murch.)
Maclurea magna (Lesu.)
Cyrtoceras scoticum (Blake.)

Professor Lapworth likewise obtained *Orthis biforata*, *Triplesia Grayi*, and *Illœnus latus*.

In the foregoing paragraphs we have described the outcrop of the Stinchar Limestone group, on the north side of the valley of the Stinchar, from Auchensoul Burn to Minuntion, along the northern limb of an anticlinal fold, where the general dip of the strata is towards the north-west. We will now refer to certain outcrops of the limestone at Dularg, on the south side of the valley opposite Auchensoul, where the calcareous series dips towards the south-east.

Dularg.—In the bed of the river Stinchar, below Dularg, the purple sandstones and conglomerate (Kirkland), the *Orthis confinis* flags, and the *Maclurea* limestone zone are met with in a highly disturbed condition. Though the strata are contorted, their general dip is to the south-east. Again, in the quarries at the farmhouse of Dularg, the limestones appear with a south-east dip, but here they have a purple tint, are much hardened and veined, and have been truncated on the south side by a powerful fault, traceable along the south side of the valley, which throws down a patch of Lower Old Red Conglomerate with its accompanying lavas. Other small exposures of reddened limestone are met with on the south side of this strip of conglomerate.

It is clear that along this part of the valley of the Stinchar the

members of the Barr series are arranged generally in the form of an anticline, with minor folds on the south-east limb. The limestone group and associated strata are not traceable for any distance on the south side, owing to the compound anticline being obliquely truncated by the powerful fault just referred to. It is highly probable, however, that the Ballantrae volcanic series lies at no great depth below the present level of the river Stinchar, between Auchensoul and Minuntion, underneath the Kirkland conglomerate. This supposition is strengthened by the fact that as we descend the valley from Minuntion to Kilpatrick and Pinmore, a distance of about a mile, the Arenig lavas and intrusive rocks appear, succeeded by coarse conglomerates, which include the *Maclurea Logani* zone of the Stinchar Limestone. The latter is met with at the northern margin of the alluvium on the north side of the Stinchar, about 300 yards east of the junction between the Stinchar and Water of Assel.

Stinchar Limestone Group in Assel Valley.—When the observer crosses the prominent ridge formed by the Benan, Kirkland, and Auchensoul Hills northwards to the Water of Assel, he finds numerous outcrops of the Stinchar Limestone beds, which are there brought to the surface apparently by means of isoclinal folds and faults. They are traceable at intervals from Craigwells to Dupin on the south side of the Water of Assel, and further to the south-west they are met with on Shalloch Hill, north-west of Daldowie. They appear further north between Tramitchell and Brockloch.

At the north-east limit of these exposures, an important section is to be seen in a deserted limestone quarry about 200 yards south of Craigwells Cottage and about half a mile E.N.E. of the farmhouse of Brockloch, where the strata have a persistent dip to the south-east. The highest bed visible on the right-hand side of the quarry is the Benan Conglomerate, which towards the base contains numerous nodules or pebbles of the Stinchar Limestone with its characteristic fossils. The conglomerate is underlain by eight feet of green shales (graptolite shales), which yielded to Professor Lapworth *Lingula*, *Acrotreta Nicholsoni*, *Diplograptus*, &c., and which rest upon the compact and nodular limestones of the Stinchar group. No beds lower than the limestone are exposed on the right-hand side of the quarry, but on the left side nodular calcareous sandstone appears, charged with *Orthis confinis*. It contains limestone nodules, with an occasional pebble of altered lava and chert, and rests unconformably on a mass of decomposing gabbro or basic rock (Ballantrae volcanic series).

In the same quarry a short distance to the south, the graptolite shales are interleaved in nodular conglomerate limestone, the sequence in descending order being: (1) Benan Conglomerate at the top, five feet; (2) shales and nodular limestone, seven feet; (3) graptolite shales, ten feet six inches. In this case also the basal beds of the Benan Conglomerate contain nodules or pebbles of the Stinchar Limestone.

Further to the south-west, the limestone quarry about 700 yards east of Brockloch Farmhouse shows the Benan Conglomerate resting apparently on an eroded surface of the limestone. Here the highest bed consists of Benan Conglomerate, containing the usual assemblage of pebbles at the base, and numerous nodules or blocks of the Stinchar Limestone, derived to all appearance from the eroded surface of the compact limestone. On the left-hand side of the quarry calcareous flagstones are visible with *Orthis confinis*.

From this quarry the limestone can be traced at intervals south-westwards to the outcrops visible on several streams near Dupin farmhouse, of which the three most important may be briefly referred to. The eastmost burn, about 550 yards E.N.E. of the farmhouse, furnishes evidence of the appearance of the Stinchar Limestone group along an isoclinal fold, in which the strata dip to the south-east. In the centre of the isocline, the *Orthis confinis* flags are met with and readily yield the zonal form. They are succeeded on both sides by the white limestone of the Stinchar group. On the north-west limb of the fold the graptolite shales plunge with an inverted dip to the south-east beneath the limestone; on the south-east side of the arch the section ceases with the limestone, no higher beds being visible.

In the Dupin Mid Burn, about 250 yards east of the farmhouse, the beds are disturbed and traversed by small faults, but there is a clear sequence from the Benan Conglomerate through calcareous shales to the compact and nodular limestones beneath. Like the sections already quoted, the basal bed of the Benan Conglomerate contains rounded nodules or pebbles of limestone, suggestive of local erosion, though Professor Lapworth is inclined to regard the relationship as probably due to faulting. The limestones are underlain by barren sandy grits.

About 400 yards west of the farmhouse of Dupin, the most complete section is visible in Dupin Glen, the beds ranging from the *Orthis confinis* flagstones to the Benan Conglomerate. In the upper part of the stream the Benan Conglomerate is well seen dipping south-east at an angle of 37°, and containing the usual assemblage of Ballantrae igneous rocks, together with pebbles of Stinchar Limestone. Underneath lie compact and nodular limestones, which yield to the Geological Survey *Maclurea Logani*. These are underlain by nodular calcareous flags, from which Professor Lapworth obtained *Orthis confinis*, *Strophomena expansa*, *Illœnus*, &c. Northwards, green conglomerate appears like that of the Benan Hill, so that it is highly probable that the northern limb of this fold may here be faulted out (Fig. 111).

From the evidence supplied by the various exposures along the line of Dupin and Craigwells, it is probable that they do not form one continuous outcrop, but occur on different folds. In one instance (Dupin East Burn) the isoclinal fold is still preserved; in others it is probable that the northern limb is truncated by faults.

Shalloch Hill.—Westwards from the outcrops just described between Craigwells and Dupin, the representatives of the Stinchar Limestone group appear along the northern margin of the inlier of volcanic and plutonic rocks on Shalloch Hill, and are exposed in two quarries at the edge of the cultivated ground. In the western opening the limestones with *Maclurea* rest upon calcareous flags, green sandy shales, and grits, from which *Orthis confinis* was obtained. These underlying strata are seen reposing, to all appearance, unconformably on a mass of gabbro to the south. The view that such is the relation of the rocks here receives support from the fact that, about 200 yards south of this quarry, in the heart of the volcanic rocks, a small outlier of the *Orthis confinis* flags comes in contact with the lavas and agglomerates. This evidence is suggestive of overlap.

In the eastern quarry, the junction of the limestone group with the igneous rocks to the south is not visible, but it is evident that the limestones are much folded and traversed by faults. North of these quarries, a mass of gabbro is exposed, which belongs to the older Ballantrae volcanic series, and in the lower portion of the Auchenmady Burn the Benan Conglomerate succeeds. On the south-east side of the volcanic "inlier," the Benan Conglomerate is faulted against the igneous rocks, and on Daldowie Hill it appears to rest unconformably on them.

From the evidence now adduced, which is by no means complete, it would seem that the existing relations of the Stinchar Limestone group to the Arenig volcanic rocks of Shalloch Hill may be accounted for by overlap, folding, and faults.

Little Letterpin.—About half a mile to the south-west of the inlier of volcanic rocks at Shalloch Hill and Daldowie, the Stinchar Limestone is exposed in an old quarry near the farm of Little Letterpin, on the west side of the Assel Water, associated with the Benan Conglomerate and containing *Maclurea Logani* and corals. In the core of this fold the underlying platform of the Ballantrae volcanic series appears as already described.

Tramitchell.—On the north side of the Water of Assel a good development of the Stinchar Limestone has been laid open in the well-known quarries at Tramitchell, where the rock is extensively quarried; indeed, next to Craighead, this place furnishes the chief supply of lime for the district. Here the beds appear along a faulted anticline, the relations of which are thus described by Professor Lapworth.

"At a first glance it would appear that at least 100 feet of compact limestone are developed at this locality, but this apparently abnormal thickness is delusive, and the limestones are actually of no greater vertical extent than elsewhere. A long strike fault bounds them to the north, throwing down against them the highest zones of the overlying Benan Conglomerate. The limestones, which include also the whole of the *Maclurea* zone, are crumpled up against this fault in a broken anticlinal form, and dip with several small step-slips, visible in the quarry

face, steadily to the southwards, as if passing below the Benar Conglomerate of the flats of Assel. The sharp anticline in the neighbourhood of the fault is well seen at the eastern extremity of the exposure. Some of the more impure and nodular beds on the floor of the quarry take on an oolitic structure, a very rare phenomenon among the limestones of the region."*

The following fossils were here collected from the limestone by the Geological Survey:

Girvanella problematica (Nich. & Eth.)	*Orthis calligramma* (Dalm.)
Saccamina Carteri (Brady.)	*Maclurea Logani* (Salt.)
Tentaculites ornatus (Sow.)	*Pleurotomaria* sp.
Atrypa hemispherica (Sow.)	*Cyrtoceras* sp.

Mrs. Gray's list contains the following additional forms from this locality: *Orthis confinis*, *Maclurea magna*; and Professor Lapworth further collected *Ecculiomphalus (Cyrtolites) Bucklandi* and *Strophomena corrugatella* (See Fig. 111).

The evidence now brought forward regarding the structural relations of the members of the Barr series in the valley of the Stinchar and in the Water of Assel proves (1) that in the valley of the Stinchar, the Stinchar Limestone group is arranged in the form of an anticline, truncated on the south side by a powerful fault; (2) that in the valley of the Assel the limestone group is brought to the surface by various sharp anticlinal folds in the midst of the Benan Conglomerate.

The original relations of the Benan Conglomerate and Stinchar Limestone group to the volcanic and plutonic rocks forming the main volcanic area of Ballantrae have been largely effaced by prominent strike faults. Nevertheless, the marked unconformability that separates the younger fossiliferous strata of the Girvan succession from the older volcanic plateau can be traced (1) round the north-east slope of the Aldons Hill, (2) near Knockbain west of Millenderdale, (3) between Byne Hill and Kennedy's Pass.

On referring to the geological map of the Ballantrae region (Sheet 7), it will be seen that the Benan Conglomerate forms a continuous belt along the northern margin of the volcanic area between Kennedy's Pass and Byne Hill, reappearing on the southern slope of the latter eminence. Southwards by Millenderdale and Aldons the conglomerate forms a similar continuous belt, lapping round the volcanic plateau. It is clear that these localities exhibit the relics of two great anticlines, the cores of which are composed of the ancient volcanic and plutonic rocks. Again, along the valley of the Stinchar from Daljarrock, by Craigneil Castle, to the mouth of the Water of Tig, a narrow belt of the unconformable fossiliferous series is thrown down by two parallel strike faults into the midst of the volcanic rocks. These include the Stinchar Limestone group, the Benan Conglo-

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 575.

merate, and possibly sediments of still younger date (Balclatchie horizon).

We shall begin our description with the sections visible in the quarries of Aldons, and trace the beds round the margin of the volcanic area towards Millenderdale and Knockbain.

Aldons.—From the elevated ridge of the Kirkland and Benan Hills the great conglomerate can be traced continuously westwards across the valley of the Assel Water north of Pinmore House to the slopes of the Aldons Hill, where the Stinchar Limestone group is well exposed. The limestones appear on both sides of a synclinal fold, the southern limb being truncated by a fault, which is prolonged eastwards to the river Stinchar near Pinmore Bridge.

The quarry which has been opened on the north-west side of the syncline supplies an excellent section of the limestone group. The lowest visible beds, which dip at a high angle to the south-east, away from the volcanic rocks, consist of purple sandy calcareous flags with scattered pebbles, decomposing readily into a sandy and muddy deposit. These are overlain by thin-bedded, flaggy and compact limestones, that yield some of the characteristic fossils of the series. The following forms were here collected by the Geological Survey:

Cythere (Cytheropsis) aldensis (M'Coy.)
Bellerophon sp.
Holopea sp.
Maclurea Logani (Salter.)
Maclurea magna (Leseur.)
Murchisonia sp.
Raphistoma sp.
Turbo sp.

From the same place Mrs. Gray has obtained the accompanying additional fossils:

Cythere aldensis var. *major* (Jones.)
,, *grayana* (Jones.)
,, *wrightiana* (Jones & Holl.)
Primitia barrandiana (Jones.)
Harpes sp.
Orthis calligramma (Dalm.)
,, *intercostata* (Port.)

In his description of this section, Professor Lapworth refers to the existence of a small fault visible at the east end of the quarry, whereby the more gently inclined Benan Conglomerate is let down against the underlying limestones. As this fault is traced along the face of the quarry to the west, certain thin-bedded greenish-grey shales appear below it, which he regards as the representative of the Kirkdominae band and the corresponding zone of Craigwells. From this highly fossiliferous zone he obtained casts of fossils of the genera *Agnostus*, *Illænus*, *Remopleurides*, *Lingula*, *Acrotreta*, and *Leptæna*, together with *Cythere* and fragments of encrinites. Professor Lapworth likewise inserts a small fault between the limestone series and the Arenig lavas on the north-west side of the quarry, but the actual contact is not visible, and it is not improbable that this junction may be an unconformable one with overlap. For a short dis-

tance to the north the conglomerate can be traced lapping round the lavas and dipping eastwards at a high angle, the boundary line forming a recognisable feature.

Along the south side of the syncline at Aldons, the limestone is visible in several quarries, where it is much disturbed by the fault that brings it in contact with the volcanic rocks. It is likewise seen in the railway cutting south of Pinmore Bridge as a faulted mass between the volcanic rocks and the overlying conglomerate to the north.

Millenderdale (Fig. 112).—Northwards from Aldons towards Chapelcroft, along the boundary line between the volcanic rocks and the overlying Benan Conglomerate, a good opportunity is afforded of studying the relation between the two. Though there is here no stream section deep enough to show the conglomerate actually resting on the lavas the two rocks are found close to each other; the conglomerate folding round the dome of volcanic rocks in such a way as to indicate that the junction is an unconformable one. A similar relation obtains along the margin of the volcanic area west of Chapelcroft towards Millenderdale. About half a mile west of the former place a thin band of limestone occurs in the conglomerate near the base of the series. The limestones, however, do not appear in force till we reach Millenderdale Farmhouse, where they are visible in certain old quarries. In the one to the east of the farmhouse *Maclurea Logani* was obtained, and in that on the west side of the farm steading, *Girvanella problematica*, *Tetradium Peachi*, and *Saccamina Carteri* were collected from the nodular flags and compact limestones.

The unconformable relation of the conglomerate series to the Arenig volcanic rocks is laid bare in a stream to the south-west of Millenderdale, and about mid-way between that point and Knockbain. This section has been figured by Professor Lapworth, and the lithological characters and physical relationships of the beds have been indicated by him. Above the fork E.N.E. of Knockbain, coarse conglomerate is associated with thin bands of shale. These shales, from which Professor Lapworth obtained *Diplograptus rugosus*, *Cryptograptus tricornis*, &c., are underlain by conglomerates and sandstones passing downwards to the coarse brecciated conglomerates that rest unconformably on the volcanic rocks. The general dip of the strata is towards the north-west, at an angle of sometimes about 70°. A careful examination of the conglomerate shows its local origin, for the pebbles consist of the surrounding volcanic and plutonic rocks, and the matrix has been derived from the disintegration of basic materials. This section tends to confirm the belief that the boundary line between the volcanic and the conglomeratic series, extending from Aldons to Millenderdale, is in the main an unconformable one.

Westwards, in the Knockbain Burn, south of the Knockbain farm-steading, green mudstones like the graptolitic mudstones appear, and still further west, at the head of a small burn about

FIG. 112.—Generalised Section across Byne Hill from Craig Skelly to Millenderdale (Length, four miles).

1B. Arenig lavas. 1. Arenig black shale. Σ. Serpentine. U. Intrusive basic rocks. G. Granite. 2a. Kirkland conglomerate.
2c. Stinchar limestone. 2e. Benan conglomerate. 3a. Balclatchie beds. 3b. Ardwell group. 3c. Whitehouse group.
3d. Barren flagstones. 4b. Craig Skelly conglomerate.

half a mile south of Barchlewan, a small exposure of shales has yielded *Climacograptus Schärenbergi*, *Diplograptus foliaceus*, &c. These shales have an inverted dip to the south-east, and are separated from the Arenig lavas by a thin mass of conglomerate.

Byne Hill and Kennedy's Pass.—Along the northern margin of the volcanic area between Byne Hill and Kennedy's Pass, the Benan Conglomerate well displays its normal lithological characters (Fig. 112). It is likewise met with on the south-east slope of Byne Hill, resting on a mass of serpentine, where, to the east of Drumfairn Farmhouse, casts of *Orthis* were obtained from a band of sandstone which is interleaved in the conglomerate, but is of small extent, since it is abruptly truncated on the east side by a fault that throws down an outlier of the Old Red Sandstone. On the north-west flank of the eruptive mass of granite and gabbro on Byne Hill, the Benan Conglomerate dips to the north-west at an angle of 60°, the junction being to all appearance an unconformable one. Here the massive conglomerate is occasionally associated with beds of sandstone and grit. But westwards, together with the overlying Balclatchie Mudstones, it is evidently faulted against the igneous rocks on the west side of the Fell Hill, south of Ardmillan Burn. Thence, along the northern flank of the Pinbain Hill, it dips north-westwards from the volcanic platform as if the junction were an unconformability. But on the shore at Kennedy's Pass, the fault is well seen that trends W. 5° N. and throws down the conglomerate and overlying Ardmillan Flags against the brecciated lavas. On the beach, below the rock-cutting marked "Kennedy's Pass" on the Ballantrae Road, a thin basalt dyke has been injected along the line of dislocation. At the south end of the Pass, where there is an ancient terrace, the present beach is occupied by brecciated lava, showing pillow-structure, followed on the seaward side by agglomerate containing blocks of various lavas, and some of a more acid type than the normal diabase of this region. The section of the Benan Conglomerate in Kennedy's Pass, which has been made classic by the descriptions of Murchison and the older observers, displays to great advantage, in cliff-section, this remarkable rock with its tumultous assemblage of pebbles of diabase, gabbro, dolerite, granite, radiolarian chert, and black shale—all of local origin (Plates XV., XVI.).

On the beach to the south-west of the Pass, a small detached patch of Benan Conglomerate, grits, and green mudstones is thrown down by a fault that runs parallel to the coast-line. The green mudstones are sparingly fossiliferous, but the following form were obtained after a considerable search: *Leptæna tenuicincta*, *L. quinquecostata*, *Ophileta compacta*, and *Bellerophon* sp.

Craigneil Castle, Colmonell.—Reference may now be made to the narrow band of the unconformable series thrown down by two parallel faults into the midst of the volcanic rocks, along the lower portion of the valley of the Stinchar, from Dal-

Benan conglomerate; shore at Kennedy's Pass, four miles south of Girvan.

jarrock by Craigneil to the mouth of the Water of Tig. The most important sections in this band occur on the south side of the Stinchar. The limestone, together with conglomerates and sandstones, is exposed in two quarries, the larger one at Craigneil Castle, and the smaller north of the road near Craigneil Farmhouse. At the latter opening the nodular limestones are underlain by brown calcareous flags with *Orthis confinis*, both zones dipping to the south-east. On the south-east side of the quarry at Craigneil Castle, the sandy calcareous bands with *Orthis confinis* reappear with an inverted south-east dip, as if resting on the limestone. Here the nodular limestone (*Maclurea* bed) and the compact limestone are visible. From these data we may infer that the members of the Stinchar Limestone group in the neighbourhood of Craigneil form an isoclinal fold, with the *Orthis confinis* beds on both sides. The various zones at Craigneil yielded to the Geological Survey *Orthis confinis*, *Maclurea magna*, and *Saccamina Carteri*. In the Cambridge Catalogue the following further forms are recorded from the same locality: *Leptæna* sp., *Maclurea Logani*, *Heliolites favosus*, and *Orthisina scotica*.

Westwards from Craigneil, by the side of the road to Salachan, and in the adjoining fields green mudstones and shales appear, which at certain localities are fossiliferous. They are either vertical or highly inclined to the north-west, and their relations to the limestone series are not apparent. A band of mudstone, on the south side of the road, about 500 yards W.S.W of Craigneil Farmhouse, furnished specimens of *Ampyx* sp., *Diplograptus rugosus*, *Turrilepas scotica*, *Pinnocaris Lapworthi*, *Acrotreta* sp., and *Ctenodonta lævis*, some of which occur in the Balclatchie Mudstones that overlie the Benan Conglomerate, to be described presently. Green mudstones and conglomerate appear in the Knockdhu Burn; and still further west, near the mouth of the Water of Tig at Heronsford, the Benan Conglomerate is visible.

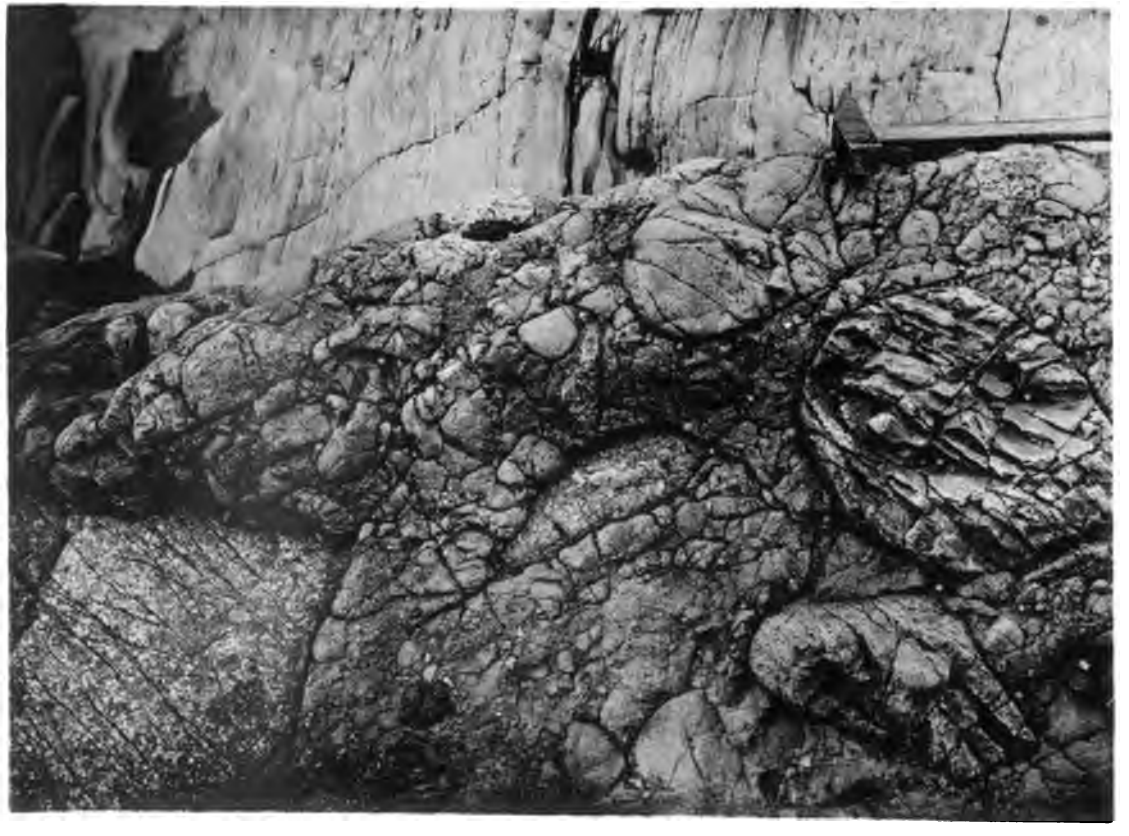
Bougang.—The limestone quarry at Bougang, situated about 300 yards south-west of the farmhouse of that name, and about two miles west of the village of Colmonell, is one of the fossiliferous localities of the Stinchar Limestone which has become widely known through the researches of the older observers. Here the beds are quite unaltered and highly fossiliferous, and yet they occur as a small isolated patch in the heart of the southern belt of serpentine. They consist of green sandy shales, which contain occasional pebbles of serpentine, alternate with flaggy limestone, and dip to the south-east, succeeded by the nodular limestones with partings of shale. The relations of these strata to the surrounding mass of serpentine are not visible, but the presence of pebbles of that rock in the shales clearly points to the limestone group being of later date. The following assemblage of organisms was here collected by the Geological Survey:

Tetradium Peachi (Nich.)
Asaphus (Isotelus) rectifrons (Portl.)
Cheirurus bimucronatus (Murch.)
Illænus (Bumastus) Bowmani (Salt.)
Phacops (Acaste) Brongniarti (Portl.)
Remopleurides laterispinifer (Portl.)
Leptæna tenuicincta (M'Coy.)
Nucleospira pisum (Sow.)
Orthis balcletchiensis (Dav.)
,, *calligramma* (Dalm.)
Orthis confinis (Salt.)
Strophomena (Rafinesquina) deltoidea (Conr.)
,, *expansa* (Sow.)
Bellerophon fastigiatus (Lindstr.)
Maclurea Logani (Salt.)
Murchisonia gyrogonia (M'Coy.)
Pleurotomaria bicincta ? (Hall.)
Holopea sp.

In the Cambridge Catalogue published by Salter and Sedgwick the following additional forms from the same place are noted: *Illænus latus*, *Orthisina scotica*, and *Murchisonia angulata*.

Knockdolian Barns.—About a mile and a quarter west of the village of Colmonell, near the farmhouse of Knockdolian Barns, on the north side of the road, another small outlying mass of the Stinchar Limestone is likewise unaltered. It consists of nodular limestone with partings of shale yielding *Maclurea* and *Saccamina Carteri*, but its relations to the adjacent rocks are not exposed.

Dinvin Hill, Pinmacher, and Glendrissock Hill (two miles south of Girvan).—Along the northern slope of the valley of the Assel, the Benan Conglomerate can be traced from the limestone quarries at Tramitchell to the Dinvin Hill, where it covers a broad area owing to reduplication by folding. The general dip of the conglomerate, where obtainable, is towards the south-east at an average angle of 25°, so that much of the plication must be isoclinal. On the north-west slope of the Dinvin Hill two isolated patches of the Stinchar Limestone occur, one about 300 yards to the north-east of Pinmacher, the second about half a mile to the north-east of that farmhouse. At the former locality the limestone dips to the south-east underneath the mass of conglomerate on Dinvin Hill, and not far to the north it is underlain by conglomerate. The horizon of this band is definitely fixed by the occurrence of *Maclurea Logani* and *Lyopora favosa*. The second locality offers but a meagre representative of the calcareous group. The nodular bands of limestone do not here exceed three feet in thickness, and are visibly overlain and underlain by conglomerates which dip in an easterly direction. In the sequel reference will be made to the fact that eastwards a regular ascending series may be traced through the Benan Conglomerate to the overlying Balclatchie grits and mudstones visible in Laggan Gill. There is likewise clear evidence to show that the outcrops of the Benan Conglomerate and overlying Balclatchie beds in Laggan Gill have been shifted by a fault trending E.N.E. and W.S.W., with a downthrow to the south-east. Hence, beyond Laggan Gill, the same zones reappear in normal order to the north of the mass of volcanic agglomerate and serpentine in Glendrissock Hill. The unconformable junction between the conglomerate and serpentine is visible in a quarry on the hill slope on the north side of Laggan Gill, while to the north the Benan Conglomerate is well



Benan conglomerate, shore four miles south of Girvan.

seen in numerous exposures, dipping northwards, away from the outlier of Arenig volcanic and plutonic rocks.

Trowier Hill (Sheet 8).—The western spur of Trowier Hill, situated between the two branches of the Piedmont Burn, that flows northwards by Doune to join the river Girvan near the harbour, is formed of a mass of Benan Conglomerate, in the midst of which serpentine protrudes with an associated vein of limestone, as on Glendrissock Hill. No outcrop of the Stinchar Limestone has been detected on this hill. The conglomerate seems here to rest unconformably on the Ballantrae plutonic rocks.

Dow Hill (Sheet 7).—Further down the Piedmont Burn an anticlinal arch of the Benan Conglomerate may be observed on the west side of that stream, on the Dow Hill, a mile and a half south of Girvan Station, where it is followed in normal sequence by highly fossiliferous Balclatchie Mudstones, to be referred to presently. The southern limb of this fold is abruptly truncated by a north-east and south-west fault, the prolongation of which is well seen in the Piedmont Burn.

Craighead (Sheet 14 of Survey Map).—On the north side of the Girvan valley, and at the eastern margin of the "inlier" of Arenig volcanic rocks, one of the celebrated exposures of the Stinchar Limestone occurs at the Craighead quarries, which have long been the chief source of lime for the district. While it is doubtless true that the typical sections in the Benan and Kirkland Burns, in the valley of the Stinchar, show more clearly the sequence and relations of the sub-divisions of the Barr series, yet the exposure at Craighead surpasses all others in the Girvan area for the prolific character of the fossiliferous zones. For this reason the locality has figured largely in the palæontological literature of the Girvan district (Fig. 109).

Reference has already been made to the fact that the "inlier" of Arenig volcanic rocks on Craighead Hill with the overlying radiolarian cherts and green mudstones is abruptly truncated on the south-east side by the great strike fault that throws down the Carboniferous rocks of the Girvan valley. At the eastern termination of this "inlier" two detached masses of Stinchar Limestone come into immediate contact with the lavas. Of these, the larger and more important exposure occurs to the north of Craighead Farmhouse, and about a mile east of Killochan Station, where two quarries have been excavated along the line of outcrop. The second and smaller mass lies about 100 yards further to the west, separated from the main body of limestone by the Arenig lavas, and truncated on the south by the great boundary fault.

The sequence and relations of the beds exposed in the two quarries traversing the more easterly mass have been described by Professor Lapworth, who states that "we have in this locality a section similar in all its details to that typical of the Stinchar calcareous series of the district to the south of the Girvan valley, the natural members of the succession corresponding precisely

in both districts in their position in the vertical series and in their petrological and palæontological characters, and differing merely in local thickness."* The physical relations of the beds, as shown by the same observer, are clearly displayed in the south quarry of the more easterly mass of limestone. The unconformable junction between the lavas and conglomerates at the base of the calcareous series is visible at the south-west end of the quarry. The beds of basal conglomerate and grit are vertical, and in places slightly inverted along the line of contact with the volcanic rocks; they are overlain by nodular limestone, charged with corals and an occasional *Maclurea*, and are traceable round the cliff that forms the west and north face of the quarry. Next in order fine compact limestone appears on the floor of the quarry and in the little cliff to the south where it is truncated by ten feet of grey and black graptolite shales, which Professor Lapworth correlates on mineralogical grounds with the *Didymograptus* shales of the Auchensoul band. From these shales Mrs. Gray has obtained *Cryptograptus tricornis* and *Diplograptus foliaceus*. Overlying these bands come greyish-yellow shales, in which Professor Lapworth identified casts of the genera *Encrinurus*, *Ampyx*, *Trinucleus*, *Leptæna*, *Strophomena*, *Orthis*, and *Cythere*. The next strata consist of conglomerate with limestone nodules.

The succession of beds now described is abruptly truncated by a fault which brings in the nodular limestones of the *Maclurea* zone, exposed in the adjoining quarry to the north-east, and underlain by nodular green and purple sandstones, resembling the *Orthis confinis* sandstone of the Stinchar valley. The calcareous strata visible in these two quarries excavated in the easterly mass of limestone at Craighead cannot be traced westwards round the inlier of Arenig volcanic rocks; indeed, the feature along the margin of the lavas is suggestive of a fault that may throw down higher members of the unconformable fossiliferous rocks of Girvan. Recently a large quarry has been opened in the westerly detached mass of limestone, about 100 yards to the west of the quarries at Craighead Farm, in which nodular and massive limestones are exposed, containing *Maclurea* and abundant corals.

The rich variety of organic remains obtained from these exposures naturally aroused the attention of palæontologists and geologists who were desirous of fixing the horizons of these beds. Guided by its palæontologists, the Geological Survey assigned the Craighead Limestone to the Caradoc formation,† a view which was at first maintained by Mr. Davidson,‡ and subsequently abandoned by him after the publication of Professor Lapworth's researches on "The Girvan Succession."§ Professor

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 583.
† Explanation of Sheet 14, one inch, p. 9.
‡ Monograph of the Silurian Brachiopoda (1864-71).
§ Supplement to the foregoing monograph (1882-84).

Nicholson, from an examination of the corals, inferred that the Craighead Limestone is of Lower Silurian age, corresponding, perhaps to the upper part of the Trenton Limestone or the beds of the Cincinnati and Hudson River formations of North America; while Mr. Etheridge, jr., on the other hand, from a consideration of the evidence supplied by the trilobites, concluded that it might be of Caradoc age.

In order that the reader may form a clear idea of the nature of the palæontological evidence on which these conclusions were based, two lists of fossils obtained from the Craighead Limestone are annexed, the first by the Geological Survey, and the second, a supplementary list by Mrs. Gray. Owing to her prolonged researches she has been able to record about 100 species of organic remains from that locality.

List of fossils from the Craighead Limestone in the collection of the Geological Survey of Scotland:

HYDROZOA.
Diplograptus rugosus (Emm.)
ACTINOZOA.
Lyopora favosa (M'Coy.)
Prasopora Grayæ (Nich. & Eth.)
Stenopora fibrosa (Goldf.)
Streptelasma craigense (M'Coy.)
TRILOBITA.
Calymene Blumenbachi (Brong.)
Encrinurus punctatus (Brünn.)
,, ,, var. *arenaceus* (Salt.)
Illænus (Bumastus) Bowmani (Salt.)
Lichas hibernicus (Portl.)
BRACHIOPODA.
Acrotreta Nicholsoni (Dav.)
Crania siluriana (Dav.)
Discina perrugata (M'Coy.)
Lingula quadrata (Eichw.)
,, *Ramsayi* (Salt.)
Leptæna Etheridgei (Dav.)
,, *sericea* (Sow.)
,, ,, var. *rhombica* (M'Coy.)
,, *(Plectambonites) transversalis* (Wahl.)
,, *youngiana* (Dav.)
Orthis balcletchiensis (Dav.)
,, *(Platystrophia) biforata* (Schl.)
,, *calligramma* (Dalm.)
,, *(Dalmanella) elegantula* (Dav.)
Orthis (Dinorthis) flabellulum (Sow.)
,, *girvanensis* (Dav.)
,, *sowerbyana* (Dav.)
,, *(Dalmanella) testudinaria* (Dalm.)
,, *vespertilio* (Sow.)
Rhynchonella æmula (Salt.)
,, *Lapworthi* (Dav.)
,, *nasuta* (M'Coy.)
,, *Peachi* (Dav.)
,, *portlockiana* (Dav.)
,, *Thomsoni* (Dav.)
,, *Weaveri* (Salt.)
Strophomena corrugatella (Dav.)
,, *(Rafinesquina) deltoidea* (Conr.)
,, *expansa* (Sow.)
,, *Grayi* (Dav.)
,, *imbrex* var. *semiglobosina* (Dav.)
,, *retroflexa* (Salt.)
Siphonotreta scotica (Dav.)
Triplesia Grayæ (Dav.)
GASTEROPODA.
Bellerophon acutus (Sow.)
Pleurotomaria sp.
CEPHALOPODA.
Orthoceras politum (M'Coy.)
,, sp.

In addition to the foregoing list of fossils in the collection of the Geological Survey, the following species are recorded in Mrs. Gray's list from Craighead:

FORAMINIFERA.
Saccamina Carteri (Brady.)
HYDROZOA.
Climacograptus bicornis (Hall.)
,, *Schärenbergi* (Lapw.)
Cryptograptus tricornis (Carr.)
Diplograptus foliaceus (Murch.)
,, sp.
Dicranograptus ramosus (Hall.)
ACTINOZOA.
Favosites girvanensis (Nich. & Eth.)
Fistulipora pilula (Nich & Eth.)
Halysites sp.
Heliolites Grayi (M. Edw.)
Lindströmia subduplicata (M'Coy.)
Monticulipora girvanensis (Nich.)
Streptelasma aggregatum (Nich. & Eth.)
Tetradium Peachi (Nich. & Eth.)
Propora Edwardsi (Nich. & Eth.)
Thecostigites scoticus (Nich. & Eth.)
CRINOIDEA.
Glyptocrinus sp.
ANNELIDA.
Cornulites sp.
TRILOBITA.
Cheirurus bimucronatus (Murch.)
Trinucleus sp.
Sphærexochus mirus (Beyr.)
BRACHIOPODA.
Lingula attenuata (Sow.)
Orthis turgida (M'Coy.)
Rhynchonella Salteri (Dav.)
,, *sub-borealis* (Dav.)
,, *scotica* (Dav.)
Strophomena rhomboidalis (Witck.)
,, *llandeiloensis* (Dav.)
Triplesia Grayæ (Dav.)
LAMELLIBRANCHIATA.
Ambonychia radiata (Emmons.)
,, *amygdalina* (Hall.)
Orthonota contracta (Hall.)
Pleurorhynchus dipterus (Salt.)
GASTEROPODA.
Bucania profunda (Hall.)
Helminthochiton sp.
Holopea paludiniformis (Hall.)
Ophileta sp.
Cyrtolites sp.
Platyceras sp.
Metoptoma sp.
Bellerophon punctifrons (Emm.)
Maclurea Logani (Salt.)
,, *macromphala* (M'Coy.)
PTEROPODA.
Conularia elongata (Portl.)
,, *Sowerbyi* (Defr.)
Ecculiomphalus Bucklandi (Portl.)
,, sp.
Hyolithes sp.
CEPHALOPODA.
Cyrtoceras scoticum (Blake.)
Orthoceras bilineatum (Hall.)
Trocholites planorbiformis (Conr.)

From the fossils given in the foregoing lists, it is apparent that the forms have a Llandeilo-Caradoc facies. The stratigraphical relations, however, clearly prove that the Craighead limestone, as shown by Professor Lapworth, is on the same horizon as the Stinchar limestone group on the south side of the Girvan valley, which is overlain by *Didymograptus* shales, containing some Glenkiln graptolites. For these reasons, we regard the Craighead limestone as of Upper Llandeilo age.

Along the north side of the Craighead volcanic area, the Stinchar Limestone group is cut out by a fault, but at the south-west termination of the "inlier" round the mansion-house of Trochraigue a considerable development of conglomerate and green shales is to be seen, which on palæontological grounds probably belong to the horizon of the Benan Conglomerate and the calcareous shales of the Stinchar Limestone. Professor Lapworth has suggested that the shales and mudstones which are visible at the little pond near the old toll-bar at Trochaigue are probably on the horizon of the *Trinucleus* mudstones of Drummuck.* But in the course of the recent revision by the Geological Survey, the fossils given in the annexed list were obtained from these shales (Fig. 109), in a burn a few yards to the north of the little pond. Green shales are there inter-

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 620.

stratified with greywacke bands, both dipping towards the N.N.W., but the beds are also traceable up the stream to the wood south of the mansion-house:

Ischadites, showing internal structure.

HYDROZOA.

Dictyonema reteforme (Hall.)
Dicranograptus ramosus (Hall.)
Diplograptus foliaceus (Murch.)

CYSTOIDEA.

Echinosphærites granulatus? (M'Coy.)

CRINOIDEA.

Crinoid stems.

ACTINOZOA.

Petraia bina (Lonsd.)
Ptilodictya dichotoma (Portl.)

TRILOBITA.

Asaphas sp.
Encrinurus punctatus (Brün.)
Illænus (Bumastus) Bowmani (Salt.)
,, sp.
Phacops (Acaste) Brongniarti (Portl.)
Trinucleus sp.

BRACHIOPODA.

Acrotreta Nicholsoni (Dav.)
Atrypa scotica ? (M'Coy.)
Discina perrugata (M'Coy.)
Leptæna sericea (Sow.)
Orthis calligramma (Dalm.)
Orthis crispa (M'Coy.)
,, *Bouchardi* var. *Balcletchiensis* (Dav.)
,, *flabellulum* (Sow.)
,, *girvanensis* (Dav.)
,, *intercostata* (Portl.)
,, *vespertilio* (Sow.)
Rhynchonella Salteri (Dav.)
,, sp.
Siphonotreta micula (M'Coy.)
Strophomena (Rafinesquina) expansa (Sow.)
,, *(Leptæna) rhomboidalis* (Wilck.)
,, sp.

LAMELLIBRANCHIATA.

Ambonychia sp.
Pterinea sp.
Pleurorynchus dipterus (Salt.)

GASTEROPODA.

Pleurotomaria (Raphistoma) lenticularis (Sow.)
,, sp.

CEPHALOPODA.

Orthoceras pendens (Blake.)

With one or two exceptions all the forms in this list have been recorded from the Stinchar Limestone group. It is highly probable, therefore, that these shales are stratigraphically not far above the horizon of the limestone.

Green shales, having a north-west dip, are likewise met with in knolls in the policies between the mansion-house and gardens, which are overlain by conglomerate, visible in the woods to the north of the policies at Trochraigue, and also in the fields between the woodlands and the farmhouse of Ladywell. Previous investigators have regarded this conglomerate as the westward prolongation of the band at the base of the Llandovery formation; but in an old quarry in a wood due north of Trochraigue Mansion-house, the following graptolites were obtained in grey shales interleaved in this conglomerate: *Dicranograptus ramosus*, *Diplograptus foliaceus*, and *Cryptograptus tricornis*. It may probably, therefore, represent the Benan Conglomerate.

Thunderton and Glenlochrie, near Kilgrammie (Sheet 14).—About a mile to the north-east of the Craighead quarries, additional exposures of the limestone group are met with in a shattered condition close to the great fault between the Silurian and Carboniferous rocks. The strata are visible in several quarries between Thunderton Hall and Glenlochrie Farmhouse, where they rest unconformably on a small patch of Arenig lava. The basal conglomerate is succeeded by sandy

calcareous bands yielding *Orthis confinis*, which are in turn overlaid by nodular limestones of the *Maclurea* zone.

Geological Horizon of the Barr Series.

The distribution and physical relations of the Benan Conglomerate and underlying Stinchar Limestone group in the Girvan region, having now been described, several points remain relating to the geological horizon of the beds to which special attention may here be directed.

(1) It has been shown that at several localities throughout the main volcanic area of Ballantrae the basal conglomerates of the Barr series rest unconformably on the volcanic and plutonic rocks of Arenig age. Similar unconformable junctions occur where the volcanic rocks form "inliers" among younger Silurian strata, as at Craigwells, Glendrissock Hill, Trowier, Craighead, and other places.

(2) The nature of the matrix of the conglomerates and the lithological characters of the pebbles conclusively prove that the materials have been locally derived from the denudation of the underlying contemporaneous and intrusive igneous rocks, together with the Middle Arenig black shales and overlying radiolarian cherts, green mudstones, and greywackes.

(3) The Stinchar Limestone group forms an important phase in this conglomeratic series, the highest zone of which (p. 485) consists of graptolite mudstones yielding a graptolite fauna, from which most of the characteristic zonal forms of the Glenkiln Shales are absent. Some of the graptolites which do occur are elsewhere confined to the Glenkiln division, while others are common to the Glenkiln and Hartfell groups.

(4) In the Girvan area lying to the north of the Stinchar valley, where the fossiliferous strata of Girvan are separated by a marked unconformability from the older volcanic rocks, no band has been found to contain the characteristic assemblage of zonal Glenkiln graptolites. Such a band, however, occurs, with many of the zonal Glenkiln forms, at the southern margin of the Ballantrae volcanic area (Portandea, Currarie), where there is a perfect passage from the Arenig lavas and overlying radiolarian cherts to the blue-black mudstones with Glenkiln graptolites.

From these data we infer that the local elevation of the area now lying to the north of the Stinchar valley took place in Llandeilo time, and was continued during a considerable interval which is elsewhere represented by the deposition of the greater portion of the Glenkiln Shales (Upper Llandeilo). Towards the close of the Llandeilo period submergence again ensued, and as the volcanic ridges slowly sank the coarse conglomerates accumulated round the old shore line. It is highly probable, therefore, that the conglomeratic series (Kirkland and Benan) and the associated limestone group belong to the close

of the Llandeilo period—a classification which may partly account for the Caradoc facies of some of the organisms found at Craighead and other localities.

During the lapse of time represented by the unconformability at the base of the Barr series, continuous sedimentation was in progress in the region lying to the south of what is now the valley of the Stinchar. The blue-black mudstones (Portandea, Currarie), charged with many of the zonal Glenkiln graptolites, the green mudstones, shales, greywackes, and pebbly grits of the "Tappins group" were then deposited on the sea-floor. Hence to the south-east of the village of Barr, a gradual intercalation of fine conglomerates sets in, composed of materials similar to those in the Benan Conglomerate and in the mudstones and shales of the "Tappins group." Though a fault does extend for a considerable distance along the south side of the valley of the Stinchar, on the southern margin of the volcanic rocks and the Benan Conglomerate, yet this dislocation can hardly be of any great amount, for the strata to the south-east of the fault are known to belong to the conformable Llandeilo series ("Tappins group"). It is interesting, too, to observe that at various localities among the conglomeratic sediments south of the Stinchar valley (Corsewall Point, Glen App, &c.) coarse boulder conglomerates appear, which contain an assemblage of pebbles similar to those in the Benan Conglomerate, including the different types of Arenig lava, the basic and plutonic rocks, radiolarian cherts, black shales, and greywackes. It is highly probable that these ancient gravels may lie on the horizon of part of the coarse boulder conglomerate of Benan. If this correlation be correct, then the strata intervening between the Glen App conglomerate and the radiolarian cherts at Portandea, north of Glen App, may approximately represent the interval marked by the unconformability north of the Stinchar valley.

The straight feature which stretches along Glen App north-eastwards by the Water of Muck, the Howe of Laggan, to the valley of the Stinchar at Aldinna marks a line of fault which was originally detected by Professor James Geikie in the course of the geological survey of that region. It is the south-westward prolongation of the great structural fault which bounds the Silurian Tableland on the north and throws down the younger Palæozoic formations against it. The continuation of this fault on the west side of Loch Ryan, where it crosses the promontory to Dally Bay, has already been referred to (p. 411).

CARADOC FORMATION.

The strata belonging to the Caradoc formation that follow in normal order the great conglomerate of Benan have a wide distribution throughout the Girvan region. They occupy that portion of the elevated plateau on the south side of the Girvan valley between the Water of Assel and the belt of Llandovery strata, extending from Saugh Hill, near Girvan, by Camregan to

the slopes of Hadyard Hill. They are likewise traceable along the shore from Kennedy's Pass northwards to Shalloch Mill, sweeping upwards to the Ardmillan Braes and Dow Hill. On the north side of the Girvan valley they form a large part of the "inlier" of Craighead and Mulloch Hill.

At the base of the Caradoc strata, and forming, as Professor Lapworth has suggested, a transition zone between the underlying Benan Conglomerate and the overlying graptolite flagstones of Ardwell and Penwhapple Glen, lies an interesting group, the Balclatchie beds, which, on account of their highly fossiliferous character, have figured prominently in the literature of the Silurian rocks of Girvan. Since the upper limit of the Benan Conglomerate is a line easily traceable in the field, and marking the close of the great conglomerate deposits, we have grouped the Balclatchie beds as the basal group of the Caradoc division. With this slight modification, we have followed the various sub-divisions of the Ardmillan series established by Professor Lapworth, as given in the annexed table in descending order:

Generalised Section of the Caradoc Strata (Ardmillan Series and Balclatchie Group).

v. Drummuck Group.	3. The sandstones and starfish beds of Quarrel Hill. 2. The trilobite mudstones of Lady Burn and Drummuck. 1. The sandstones and grits of Auldthorns.
iv. Barren Flagstone Group. -	Flagstones, shales, and mudstones.
iii. Whitehouse Group.	2. Green and purple mudstones, with calcareous seams. 1. Shales with bands of calcareous grit.
ii. Ardwell Group.	3. Green grits and mudstones (cascade beds). 2. Thin-bedded flags and rusty shales. 1. Iron-stained shales and mudstones (Knockgerran).
i. Balclatchie Group.	2. Fossiliferous grits and conglomerates. 1. Nodular mudstones, highly fossiliferous.

We shall describe first of all the distribution of the Caradoc strata on the south side of the Girvan valley, and thereafter, their development in the Craighead "inlier."

i. *Balclatchie Group.*

Balclatchie Bridge, Penwhapple Burn.—About two miles to the north-west of Barr, on the high-road between that village and Girvan, the passage is well seen from the Benan Conglomerate to the overlying mudstones and grits of the Balclatchie group. Here the highest beds of the conglomerate are traversed by the Penwhapple Burn, where it has carved a

small gorge between the Green Hill to the north and the Doon Hill near Balclatchie. On the cliff by the roadside eastwards from the bridge the successive beds of conglomerate appear charged with pebbles of the usual volcanic and plutonic rocks, lying in a matrix derived from the disintegration of basic materials. They dip to the E.N.E. at an angle of about 60°, and are succeeded by a zone of dark green nodular calcareous mudstones, with certain marked lithological characters. At the first glance they recall in their appearance and mode of weathering the graptolitic mudstones that overlie the Stinchar Limestones in Benan Burn. Where they are fresh, they break under the hammer into angular fragments with a conchoidal fracture; where weathered, their joints are coated with yellow iron-oxide. They are exposed by the roadside, in the bed of the Penwhapple Burn (which joins the Girvan Water near Killochan), and also in a small cliff on the south bank of the stream. The rich variety and remarkable preservation of the organic remains obtained from these mudstones are, however, their striking features. Upwards of 100 species have been recorded from the exposures of these nodular mudstones at this locality. In order to furnish the reader with a complete enumeration of the fossils, two lists are annexed, the first embracing the forms in the collection of the Geological Survey, the second comprising additional species obtained by Mrs. Gray. The first list is as follows:—

Nidulites favus (Salt.)

HYDROZOA.

Climacograptus sp.

ACTINOZOA.

Ptilodictya dichotoma (Portl.)

CIRRIPEDIA.

Turrilepas scotica (Nich. & Eth.)

PHYLLOCARIDA.

Peltocaris sp.
Pinnocaris Lapworthi (Eth. jun.)

TRILOBITA.

Acidaspis Grayæ (Eth. jun.)
,, *hystrix* (Wyv. Thom.)
Agnostus agnostiformis (M'Coy.)
Ampyx Hornei (Eth. & Nich.)
,, *Maccallumi* (Salt.)
Asaphus (Isotelus) gigas (Dekay.)
Barrandia sp.
Bronteopsis scotica (Salt.)
Bronteus Andersoni (Eth. & Nich.)
Cheirurus gelasinosus (Portl.)
,, sp.
Cybele verrucosa (Dalm.)
Illænus (Bumastus) Bowmani (Salt.)
,, *(Dysplanus) Thomsoni* (Salt.)
,, sp.
Lichas hibernicus (Portl.)
Phacops (Acaste) Brongniarti (Portl.)
Proetus girvanensis (Eth. & Nich.)
Remopleurides Barrandei (Eth. & Nich.)
Remopleurides laterispinifer (Portl.)
Salteria primæva (Wyv. Thom.)
Staurocephalus globiceps (Portl.)
,, *unicus* (Wyv. Thom.)
Trinucleus Macconochiei (Eth. & Nich.)

BRACHIOPODA.

Acrotreta Nicholsoni (Dav.)
Discina oblongata (Portl.)
,, *perrugata* (M'Coy.)
Leptæna (Plectambonites) quinquecostata (M'Coy.)
,, *(scissa)=llandeiloensis* (Dav.)
,, *sericea* (Sow.)
,, ,, var. *rhombica* (M'Coy.)
,, *(Christiania) tenuicincta* (M'Coy.)
Lingula attenuata (Sow.)
,, *ovata* (M'Coy.)
,, *Ramsayi* (Salt.)
Orthis balcletchiensis (Dav.)
,, *(Dalmanella) elegantula* (Dalm.)
,, *sowerbyana* (Dav.)
Paterula (Discina) balcletchiensis (Dav.)
Siphonotreta micula (M'Coy.)
Strophomena corrugatella (Dav.)
,, *(Rafinesquina) deltoidea* (Conr.)

Strophomena imbrex (Pand.)
,, *(Leptæna) rhomboidalis* (Wilck.)

LAMELLIBRANCHIATA.

Ctenodonta anglica (D'Orb.)
,, sp.

GASTEROPODA.

Bellerophon acutus (Sow.)
,, *bilobatus* (Sow.)
,, *dilatatus* (Sow.)
Ecculiomphalus Bucklandi (Portl.)
Murchisonia gyrogonia (M'Coy.)
Raphistoma æqualis (Salt.)

PTEROPODA.

Hyolithes sp.

CEPHALOPODA.

Lituites sp.
Orthoceras politum (M'Coy.)
,, *subundulatum* (Portl.)

The following supplementary list shows the additional species obtained by Mrs. Gray.

Ischadites Kœnigi (Nich. & Eth.)

HYDROZOA.

Dicranograptus tardiusculus (Lapw.)
Diplograptus rugosus (Emm.)

CRINOIDEA.

Glyptocrinus sp.
Myelodactylus sp.

ACTINOZOA.

Retepora sp.

TRILOBITA.

Acidaspis Lalage (Wyv. Thom.)
Cheirurus Sedgwicki (M'Coy.)
Deiphon Forbesi (Barr.)
Harpes sp.
Lichas Grayi (Flet.)
Sphærexochus mirus (Beyr.)

BRACHIOPODA.

Lingula canadensis (Bill.)
,, *granulata* (Phil.)
Stricklandinia balcletchiensis (Dav.)
Rhynchonella balcletchiensis (Dav.)
,, *cuneatella* (Dav.)
,, *girvanensis* (Dav.)
,, *nasuta* (M'Coy.)
Rhynchonella portlockiana (Dav.)
,, *nucula* (Sow.)
Orthis calligramma var. *virgata* (Salt.)
,, ,, var. *plicata* (Sow.)
Strophomena semiglobosina (Dav.)

LAMELLIBRANCHIATA.

Ctenodonta levata (Hall.)
Nucula subacuta (M'Coy.)

GASTEROPODA.

Bellerophon expansus (Sow.)
,, *bilobatus* (Sow.)
Bucania sp.
Cyrtolites sp.
Ecculiomphalus lævis (Sow.)
Murchisonia simplex (M'Coy.)
Raphistoma sp.

PTEROPODA.

Conularia elongata (Portl.)
Hyolithes acutus (Eichw.)
,, *operculatus* (Salt.)
,, *reversus* (Portl.)

CEPHALOPODA.

Endoceras strangulatum (Hall.)

These nodular mudstones are succeeded by green sandstones and conglomerates, which likewise form an important horizon owing to the fossiliferous character of the conglomerates. Like the Benan Conglomerate, the matrix of the beds above the Balclatchie mudstones is largely composed of the detritus of the Arenig igneous rocks, and the scattered pebbles are formed of similar materials. The fossiliferous conglomerate is overlain by green sandstones which pass upwards into iron-stained shales with graptolites that form the lowest sub-division of the Ardwell group. The fossils obtained from the Balclatchie Conglomerate by the Geological Survey, are given in the following list:—

Illænus (Bumastus) Bowmani (Salt.)
Acrotreta Nicholsoni (Dav.)
Leptæna (Christiania) tenuicincta (M'Coy.)
Orthis calligramma (Dalm.)
,, *balcletchiensis* (Dav.)
,, *sowerbyana* (Dav.)
Rhynchonella nasuta (M'Coy.)
,, *nucula* (Sow.)
Strophomena corrugatella (Dav.)
,, *(Rafinesquina) deltoidea* (Conr.)
,, *semiglobosina* (Dav.)

The following are the additional species obtained by Mrs. Gray.

Fistulipora favosa (Nich. & Eth.)
Ampyx sp.
Cheirurus bimucronatus (Murch.)
Sphærexochus mirus (Beyr.)
Lingula canadensis (Bill.)
Leptæna sericea var. *rhombica* (M'Coy.)
,, *(Plectambonites) transversalis* (Dalm.)
,, *youngiana* (Dav.)
Orthis Bouchardi var. *balcletchiensis* (Dav.)
,, *Lapworthi* (Dav.)
Orthis turgida (M'Coy.)
Rhynchonella balcletchiensis (Dav.)
,, *cuneatella* (Dav.)
,, *girvanensis* (Dav.)
,, sp.
Strophomena retroflexa (Salt.)
Pleurorhynchus dipterus (Salt.)
Bellerophon sp.
Cyrtolites orbicularis (Lindst.)
Raphistoma æqualis (Salt.)
Maclurea matutina (Hall.)
Cyrtoceras sp.
Phragmoceras sp.

Barbae, Daldowie, and Millenderdale. (Sheets 7 and 8).—From Balclatchie Bridge south-westwards to Tramitchell, considerable difficulty has been found in tracing the outcrop of the Balclatchie group, for in that district the line marking the upper limit of the Benan Conglomerate is very irregular, owing to the reduplication of the strata by folding. Hence long tongues of conglomerate and grit penetrate in anticlinal form the graptolitic shales and mudstones, while the latter lie in synclines of the underlying beds. Professor Lapworth has obtained fossils in grits at various localities along this line of outcrop—as, for instance, near the limestone quarry at Tramitchell, near the farmhouse of Barbae, and in quarries west of the Dalfask Burn. Regarding the outcrop by the roadside near Barbae Farmhouse. he states that the grit "there abounds in fragments of quartz, and, except for its decidedly gritty matrix, has few points of resemblance to the typical Balclatchie grit. It contains a few fossils in some shaly seams at its summit: *Leptæna*, *Bellerophon*, and *Ctenodonta* were here collected by myself."* Another exposure of a similar fossiliferous grit occurs in the Water of Assel, about 700 yards N.N.E. of Pinmerry, where numerous casts of fossils occur, including corals, brachiopods, and encrinites.

On the western slope of Daldowie Hill, a rapid reduplication of the Benan Conglomerate and overlying mudstones, similar to that near Balclatchie, is observable. So marked is the folding that the observer cannot fail to realise how largely the great development of the conglomerate between the Stinchar and the Assel Water may be due to the plication of the beds. From the shales on Daldowie Hill Professor Lapworth obtained *Strophomena corrugatella*, *Leptæna sericea*, *Ctenodonta*, and a form of *Ampyx*. Immediately to the east of these highly folded strata (Balclatchie Shales and Benan Conglomerate) occurs a small inlier of volcanic agglomerate bounded on the east side by an outcrop of Stinchar Limestone.

Beyond the valley of the Assel in the direction of Millenderdale, fossiliferous grit, evidently on the horizon of the Bal-

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 589.

clatchie Grit, is found in quarries on the north side of the road near Meikle Letterpin. Again, in the south branch of Millenderdale Burn, north-west of Knockbain Farmhouse, greenish mudstones dip to the north-west at high angles and immediately overlie the Benan Conglomerate, from which the following fossils have been obtained, indicating the horizon of the Balclatchie Mudstones:

Turrilepas scotica (Nich. & Eth.)	*Lingula attenuata* (Sow.)
Illœnus sp.	*Ctenodonta lævis* (M'Coy.)
Remopleurides sp.	*Bellerophon fastigiatus* (Lindst.)
Leptæna sericea (Sow.)	*Cyclonema* sp.

Laggan Gill (Sheet 7).—On the south-west side of the gorge of Laggan Gill, and about 400 yards west of the farmhouse of Laggan, the Balclatchie shales and grits, as shown by Professor Lapworth, plunge with an inverted dip underneath the Benan Conglomerate. Here the transition zone at the summit of the group is crowded with characteristic graptolites and brachiopoda in a state of fine preservation, the commonest forms recorded by Professor Lapworth being: *Cryptograptus tricornis*, *Lasiograptus Harknessi*, *Climacograptus bicornis*, *C. Schärenbergi*, *Diplograptus ruqosus*, *D. foliaceus*, together with species of *Trachyderma*, *Cythere*, &c. During the recent revision by the Geological Survey the following graptolites were obtained from limestone nodules in shales, passing with an inverted south-west dip beneath the Balclatchie Grit of Laggan Gill, viz.: *Diplograptus foliaceus*, *Dicranograptus ramosus*, *Climacograptus Schärenbergi*, and *Orthoceras*.

Ardmillan Braes (two miles south of Girvan).—Next to the exposures at Balclatchie Bridge the outcrop of the Balclatchie group at Ardmillan Braes is deserving of notice on account of the rich variety of its organic remains. As described on a previous page, the successive bands of Benan Conglomerate are traceable along the hill slopes from Kennedy's Pass by Shiel Hill to the declivity south of Ardwell and Ardmillan. Throughout part of this distance, as in the streams S.S.W. of Ardwell, the conglomerate dips to the north-west at an angle of about 50° underneath the graptolite flagstones, but towards the slope south of Ardmillan House the beds are vertical and in some cases inverted. Here the highly fossiliferous mudstones are exposed in old quarries about half a mile E.S.E. of Ardwell Farmhouse, and a continuous section can be followed northwards in several small streamlets from the underlying Benan Conglomerate to the mudstones. As Professor Lapworth has shown, the conglomerate in the stream sections is succeeded northwards by greenish grey grits, that weather with a purple tint and have a highly inverted dip to the S.S.E.; these are followed by calcareous sandstones, which are very fossiliferous on certain horizons, having yielded to him *Remopleurides dorsospinifer*, *Asaphus gigas*, *Staurocephalus globiceps*, *Phacops Bronqniarti*, *Orthis calligramma*, *O. actoniæ*, *Leptæna tenuicincta*, *Murchisonia*, &c. After a short gap in the section, the green nodular mudstones reappear in the

quarries and in the streamlets, with their characteristic lithological and palæontological features.

Regarding the sequence of the strata visible at Ardmillan Braes, Professor Lapworth makes the following statement:—"The relation of the fossiliferous Balclatchie Sandstones to the Benan Conglomerate at this locality is presumptive of a dislocation between the two, and if the natural sequence contains the same members as at Balclatchie, the beds here in contact with the conglomerate must be the highest beds, the fossiliferous mudstones being the lowest strata of the transitional groups here exposed and owing their great thickness to their being arranged in anticlinal form. The hiatus in the succession would naturally be filled with graptolitiferous mudstones, over which follow the shell-bearing gritstones in their proper sequence. If this be the true interpretation of the visible phenomena, it follows that the shell-bearing gritstones should be repeated between these quarries and the graptolitic flagstones visible in the roadway, or must be again cut out by a fault. That the latter supposition is in all probability the correct one is evident from the fact that where the sequence is unbroken, a quarter of a mile to the westward, it is identical with that at Balclatchie, as is also the case in Ardmillan Burn, about half a mile further to the east." *

The following list gives the fossils in the collection of the Geological Survey from the Balclatchie beds, Ardmillan Braes:

Stenopora (Favosites) fibrosa (Goldf.)
Petraia elongata (Phil.)
Asaphus (Isotelus) gigas (Dekay.)
,, ,, *rectifrons* (Portl.)
Bronteus hibernicus (Portl.)
Harpes sp.
Illænus Bowmani (Salt.)
Phacops (Acaste) Brongniarti (Portl.)
,, *Dalmani* (Portl.)
Staurocephalus globiceps (Portl.)
Stygina latifrons (Portl.)
Trinucleus sp.
Acrotreta Nicholsoni (Dav.)
Discina oblongata (Portl.)
,, ,, var.
Leptæna (scissa)=llandeiloensis (Dav.)
,, *sericea* (Sow.)
,, *(Orthis) Rankini* (Dav.)
,, *(Christiania) tenuicincta* (M'Coy.)
Orthis (Dalmanella) testudinaria (Dalm.)
,, *calligramma* (Dalm.)
,, ,, var. *virgata* (Sow.)
,, *(Dalmanella) elegantula* (Dalm.)
Rhynchonella cuneatella (Dav.)
Strophomena arenacea (Salt.)
,, *(Rafinesquina) expansa* (Sow.)
,, *grandis* (Sow.)
Ambonychia sp.
Arca edmondiæformis (M'Coy.)
Ctenodonta sp. (4)
Cucullella sp.
Modiolopsis modiolaris (Conr.)
Orthonota sp. (2)
Bellerophon acutus (Sow.)
,, *carinatus* (Sow.)
,, *trilobatus* (Sow.)
Cyclonema crebristrium (M'Coy.)
Ecculiomphalus minor (Portl.)
,, *scoticus* (M'Coy.)
Holopea sp.
Holopella sp.
Maclurea sp.
Murchisonia sp.
Ophileta compacta (Salt.)
Raphistoma lenticularis (Sow.)
Conularia elongata (Portl.)
Hyolithes (Theca) reversus (Salt.)
,, *triangularis* (Salt.)
,, *vaginulus* (Salt.)
Orthoceras ibex (Sow.)
,, *imbricatum* (Wahl.)

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 591.

The following supplementary list of fossils shews the forms obtained by Mrs. Gray in addition to those given in the foregoing list:

Dicellograptus moffatensis (Carr.)
Dicranograptus tardiusculus (Lapw.)
Diplograptus sp.
Glyptocrinus sp.
Ptilodictya dichotoma (Portl.)
Turrilepas scotica (Eth. & Nich.)
Pinnocaris Lapworthi (Eth. jun.)
Agnostus agnostiformis (M'Coy.)
Ampyx Hornei (Eth. & Nich.)
Bronteopsis scotica (Salt.)
Cheirurus sp.
Cybele verrucosa (Dalm.)
Crania sp.
Discina perrugata (M'Coy.)
Leptæna llandeiloensis (Dav.)
,, *(Plectambonites) quinquecostata* (M'Coy.)
Lingula attenuata (Sow.)
,, *brevis* (Portl.)
,, *granulata* (Phill.)
Orthis calligramma (Dalm.)
,, ,, var. *plicata* (Sow.)
,, *Carausii* (Salt.)
,, *crispa* (M'Coy.)
,, *(Dinorthis) flabellulum* (Sow.)
,, *kilbuchoensis* (Dav.)
,, sp.
Rhynchonella ardmillanensis (Dav.)
,, sp.
Siphonotreta micula (M'Coy.)
Strophomena compressa (Sow.)
,, *corrugatella* (Dav.)
,, *(Rafinesquina) deltoidea* (Conr.)
,, *insculpta* (Hall.)
,, *llandeiloensis* (Dav.)
,, *retroflexa* (Salt.)
,, sp.
Triplesia spiriferoides (M'Coy.)
Ambonychia radiata (Emm.)
,, sp.
Avicula sp.
Ctenodonta astartæformis (Salt.)
,, *varicosa* (Salt.)
Goniophora sp.
Bellerophon bilobatus (Sow.)
,, *expansus* (Sow.)
,, sp.
Bucania sp.
Ecculiomphalus Bucklandi (Portl.)
Pleurotomaria trochiformis (Portl.)
Raphistoma sp.
Pterotheca transversa (Salt.)
Orthoceras Avelini (Salt.)

Dow Hill, Sheet 7).—In a quarry on the northern slope of the arch of Benan Conglomerate on Dow Hill, a mile and a half south of Girvan Station, the Balclatchie Mudstones occupy their normal position and yield their characteristic fossils. The fossils given in the subjoined list have been collected there by the Geological Survey:

Agnostus agnostiformis (M'Coy.)
Ampyx Maccallumi (Salt.)
Asaphus (Isotelus) gigas (Dekay.)
Cybele sp.
Phacops (Acaste) Brongniarti (Portl.)
Remopleurides Barrandei (Eth. & Nich.)
,, *laterispinifer* (Portl.)
Staurocephalus unicus (Wyv. Thom.)
Trinucleus ornatus (Sternb.)

The following additional forms have been obtained by Mrs. Gray from the same locality:

Diplograptus sp.
Glyptocrinus sp.
Ptilodictya dichotoma (Portl.)
,, sp.
Tentaculites sp.
Turrilepas scotica (Eth. & Nich.)
Ampyx Hornei (Eth. & Nich.)
Cybele verrucosa (Dalm.)
Lichas sp.
Staurocephalus globiceps (Wyv. Thom.)
Trinucleus concentricus (Eaton.)
Discina oblongata (Portl.)
Lingula attenuata (Sow.)
Orthis (Dalmanella) testudinaria (Dalm.)
Strophomena corrugatella (Dav.)
,, *retroflexa* (Salt.)
,, *(Rafinesquina) deltoidea* (Conr.)
Rhynchonella sp.
Ambonychia sp.
Ctenodonta astartæformis (Salt.)
Bellerophon bilobatus (Sow.)
Bucania sp.
Raphistoma sp.
Helminthochiton sp.
Ecculiomphalus Bucklandi (Portl.)
Conularia elongata (Portl.)
Hyolithes reversus (Portl.)
Endoceras strangulatum (Hall.)
Orthoceras subundulatum (M'Coy.)

Folded flagstones and shales (Ardmillan Series), shore 3¾ miles south of Girvan.

Ardmillan Shore.—Having indicated the chief localities where the highly fossiliferous Balclatchie beds are visible, we may now describe two prominent sections on the south side of the Girvan valley, which display the three succeeding subdivisions of the Caradoc strata, viz.: the Ardwell group, the Whitehouse group, and the Barren Flagstone group. The first of these, which extends along the shore from Kennedy's Pass to Shalloch Mill—a distance of about three miles—has been chosen by Professor Lapworth as a typical section of the graptolitic flagstone series (Fig. 113). The second occurs in Penwhapple Glen, to the north-west of Balclatchie Bridge.

ii. *Ardwell Group.*

The Ardmillan shore section (Fig. 113), furnishes at low tide a tolerably continuous sequence of these groups. At the northern limit of Kennedy's Pass the Benan Conglomerate is followed immediately by the basal zones of the Ardwell group. Though every bed at the line of contact is visible, there is here no representative of the intervening Balclatchie group, which is met with, as already indicated, about a mile and a half to the east on Ardmillan Braes.

The lowest zones consist of thin dark grey slightly carbonaceous shales with hard grey ribs, from which Professor Lapworth has collected the following graptolites:—*Diplograptus foliaceus*, *D. pristis*, *D. rugosus*, and *Climacograptus bicornis*. These strata are followed by flaggy shales passing upwards at the farm of Ardwell into flagstones with partings of dark grey shale. From these beds the same observer obtained in addition to the fossils of the lower zones: *Dicranograptus ramosus*, *Corynoides calycularis*, *Ecculiomphalus Bucklandi*, and an occasional brachiopod. The highest members visible on the beach at Ardwell consist of banded shales with alternating dark and grey seams charged with *Climacograptus caudatus* and *Diplograptus rugosus* (3b^6, Fig. 113).

Though the section from Kennedy's Pass to Ardwell Bay does not show the Cascade beds, which Professor Lapworth regards as the highest sub-zone of the Ardwell group, it affords excellent opportunities for studying the peculiar types of the graptolitic flagstones and the rapid folding of the strata (Plate XVII.). This striped flagstone series includes the representatives of only a portion of the Lower Hartfell black shale of the Southern Uplands, and by means of the zonal form *Climacograptus caudatus* it is possible to fix the stratigraphical horizon of the beds in Ardwell Bay relatively to the Moffat sequence. Instead of a limited thickness of black shales, we have here a succession of striped flagstones and shales, which is probably not far short of 1000 feet in thickness.

iii. *Whitehouse Group.*

From Ardwell Bay north-eastwards along the shore to Shalloch Mill, the members of this group are well exposed. They

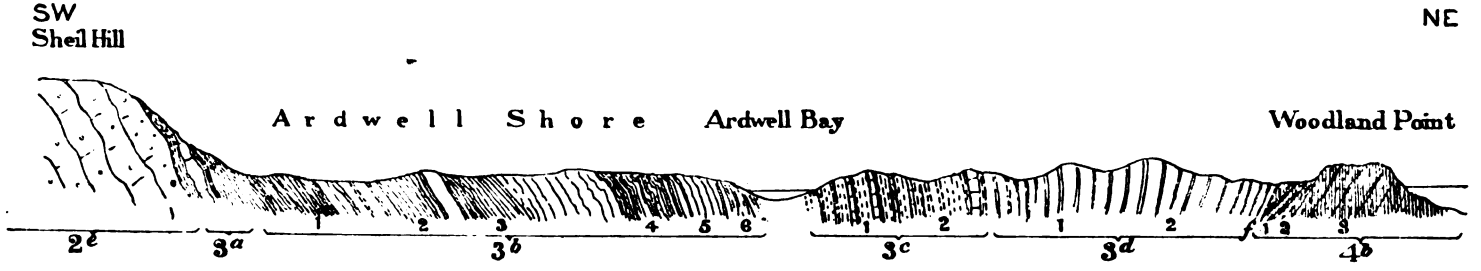


FIG. 113.—Section of the Strata on Ardmillan Shore, Ayrshire (after Lapworth).

4b. Woodland beds (Llandovery).
3. Grits and conglomerates.
2. Carbonaceous shales with *Climacograptus rectangularis*, &c.
1. Lower *Pentamerus* limestone.

3d. Barren flagstones.
2. Flagstones and shales, non-fossiliferous.
1. Shales with *Nematolites*.

3c. Whitehouse beds.
2. Mudstones and flags with *Dicellograptus complanatus*.
1. Shales and calcareous grits with *Leptæna sericea* and *L. transversalis*.

3b. Ardwell beds.
6. Flaggy shales with *Climacograptus caudatus*.
5. Flaggy beds with *Dicranograptus ramosus*.
3 & 4. Splintery iron-stained shales with *Corynoides calycularis*.
2. Hard grey flags and shales with *Diplograptus rugosus*.
1. Iron-stained dark shales with few fossils.

3a. Balclatchie beds.
2e. Benan conglomerate.

have been arranged by Professor Lapworth in two sub-groups. The lower consists of (1) grey and green carbonaceous shales, yielding *Dicellograptus Forchhammeri*, followed by (2) grey flagstones with ribs of impure fossiliferous limestone, enclosing specimens of *Leptæna transversalis*, *L. sericea*, *Orthis calligramma*, *Strophomena* sp.; (3) soft green mudstones with hard siliceous ribs. These sub-zones are displayed on the beach northwards from Ardwell Bay, the beds being vertical or highly inclined, and in some cases inverted. At the third milestone from Girvan, beside the old ruin of Whitehouse, the variegated mudstones, shales, flags, and calcareous bands are well seen that form the upper sub-group and contain certain highly fossiliferous seams. The lowest beds of the upper sub-group are readily recognised from the presence of a zone of bright purple mudstones, conspicuous on the beach at low tide, which are associated with alternating green and purple mudstones and shales. These strata are destitute of fossils, but they pass upwards into calcareous grits, flagstones, and shales, with black shale seams, some of the bands being highly fossiliferous.

The fossils given in the following list have been obtained by Mrs. Gray from this group in Whitehouse Bay.

Dicellograptus Morrisi (Hopk.)
Diplograptus quadrimucronatus (Hall.)
,, *socialis* (Lapw.)
,, *truncatus* (Lapw.)
Serpulites longissimus (Murch.)
Turrilepas Peachi (Eth. jr.)
Aparchites leperditioides (Jones.)
,, *subovatus* (Jones.)
Beyrichia Kloedeni var. *infecta* (Jones.)
,, *impar* (Jones.)
Cypridina Grayæ (Jones.)
Primitia girvanensis (Jones.)
,, *Grayæ* (Jones.)
,, *Krausei* (Jones.)
,, *mundula* var. *fimbriatus* (Jones.)
,, *nuda* (Jones.)
,, *ulrichiana*.
Sulcuna præurrens (Jones.)
Ulrichia girvanensis (Jones.)
Agnostus perrugatus (Barr.)
Ampyx sp.
Bohemilla sp.
Cyclopyge armata (Barr.)
,, *rediviva* (Barr.)
Cybele sp.
Dindymene Cordai (Eth. & Nich.)
Dionide Lapworthi (Eth. & Nich.)
Trinucleus sp.
Athyris sp.
Lingula attenuata (Sow.)
,, *brevis* (Portl.)
Orthis sp.
Euomphalus sp.
Hyolithes (Theca) triangularis (Portl.)
,, ,, *reversus* (Salt.)
Orthoceras bullatum (Sow.)

To the north of the old ruin of Whitehouse, the Upper Whitehouse beds are followed seawards by the Barren Flagstones of the succeeding group, but their strike being nearly parallel to the shore, they can be traced at intervals north-eastwards along the margin of the beach to Port Cardloch, thence across Woodland Point to Woodland Bay, and onwards to Myoch Bay, opposite Shalloch Mill and south of Craigskelly where a fine development of the upper sub-division has been minutely described by Professor Lapworth (Quart. Jour. Geol. Soc., vol. XXXVIII., p. 599). The relations of the strata are here somewhat complicated owing to inversion and folding. The overlying Barren Flagstones dip south-eastwards underneath the Upper

Whitehouse beds, showing how misleading is evidence based merely on local relative superposition. In the centre of Myoch Bay, between Shalloch Mill and the mouth of Byne Hill Burn, the beds are highly contorted, but towards the south-west the sub-zones of purple and variegated mudstones are recognisable, and are succeeded northwards by the richly fossiliferous bands that form the highest sub-division of the Upper Whitehouse beds. The latter, as developed on the beach opposite Shalloch Mill, are thus described by Professor Lapworth.

"The final or fossiliferous sub-group is greatly contorted and broken, but when carefully mapped in detail, the following succession is easily made out:

"(1) *Dicellograptus-complanatus* zone. Black shales, highly carbonaceous, with a few seams of grey mudstone and calcareous grit, crowded with graptolites (5 feet). *Diplograptus socialis* (Lapw.) is the commonest form, and occurs in hosts. Less frequent are the forms in the following list:

Climacograptus tubuliferus (Lap.)
Dicellograptus complanatus (Lapw.)
,, *Morrisi* (Hopk.)
Theca triangularis (Portl.)
Lingula sp.

"(2) *Dictyonema*-zone. Hard flaggy shales (9 feet) with ribs of grey calcareous rocks. In certain zones these beds contain an abundance of *Dictyonema*, together with numerous fragments of *Phyllopoda*, *Lingulidæ*, and *Diplograptidæ*.

"The characteristic forms are *Dictyonema*, *Ganocladium*, *Lingula*.

"(3) *Dionide*-beds. Finally we have a thickness of about six feet of sandstones, containing such a large proportion of calcareous matter that in places they rather deserve the title of impure nodular limestones. They afford a large and varied association of fossils, some of which are beautifully preserved."

The fossils given in the subjoined list have been collected by Mrs. Gray from these fossiliferous bands on the beach opposite Shalloch Mill:

Climacograptus tubuliferus (Lapw.)
Diplograptus sp.
Halysites catenulatus (Linn.)
,, sp.
Glyptocrinus sp.
Nematolites Grayi (Lapw.)
Tentaculites anglicus (Salt.)
Fenestella sp.
Calymene Blumenbachi (Brong.)
,, sp.
Cybele sp.
Illænus sp.
Staurocephalus globiceps (Portl.)
Trinucleus sp.
Discina perrugata (M'Coy.)
Leptæna segmentum (Ang.)
,, *(Plectambonites) quinquecostata* (M'Coy.)
,, *sericea* (Sow.)
Leptæna (Christiania) tenuicincta (M'Coy.)
,, *(Plectambonites) transversalis* (Wahl.)
Lingula attenuata (Sow.)
,, *brevis* (Portl.)
,, *quadrata* (Eichw.)
Orthis (Bilobites) biloba (Linn.)
,, *calligramma* (Dalm.)
,, *(Dalmanella) elegantula* (Dalm.)
,, *Lapworthi* (Dav.)
,, *sowerbyana* (Dav.)
,, *(Dalmanella) testudinaria* (Dalm.)
,, *vespertilio* (Sow.)
Pentamerus shallockiensis (Dav.)
Porambonites intercedens (Pand.)
Crania (Pholidops) implicata (Sow.)

Rhynchonella shallockiensis (Dav.)
Skenidium shallockiensis (Dav.)
Strophomena corrugatella (Dav.)
,, *rhomboidalis* (Wilck.)
,, *shallockiensis* (Dav.)
,, *simulans* (M'Coy.)
Ambonychia radiata (Emm.)
Mytilus gradatus (Salt.)
Bellerophon argo (Bill.)
,, *carinatus* (Sow.)
,, sp.
Cyclonema carinatum (Sow.)
Ecculiomphalus Bucklandi (Portl.)
,, *lævis* (Sow.)
Euomphalus funatus (Sow.)
Metoptoma sp.
Murchisonia (*Pleurotomaria*) *bicincta* (Hall.)
Ophileta compacta (Salt.)
,, *Nerine* (Bill.)
Oriostoma discors (Sow.)
Pleurotomaria sp.
Orthoceras arcuoliratum (Hall.)
,, *bilineatum* (Hall.)
,, *gracile* (Portl.)
,, *ludense* (Sow.)
,, *vagans* (Salt.)

Near the mouth of the Byne Hill Burn, close to Shalloch Mill, from an outcrop of soft blue flaggy mudstones with black carbonaceous seams, Professor Lapworth obtained an important suite of graptolites characteristic of the *Pleurograptus linearis* zone, which are given in the following list:

Leptograptus flaccidus (Hall.)
Pleurograptus linearis (Carr.)
Dicellograptus Morrisi (Hopk.)
Climacograptus tubuliferus (Lapw.)
Diplograptus quadrimucronatus (Hall.)
,, *foliaceus* (His.)

Regarding these beds the same observer states that they "are of the same general character as those of the majority of the Whitehouse group, to which they unquestionably belong; but the absence of definite ribs of flagstone from among the soft blue shaly mudstones, of which these Byne Hill beds are made up, will not allow us to parallel the little group satisfactorily with any of the zones already described."

iv. *Barren Flagstone Group.*

The next group of strata above the Whitehouse beds, consists of alternations of flagstones and shales with greywacke bands, and is singularly destitute of organic remains. It is traceable along the shore in a nearly vertical position from Whitehouse to near Shalloch Mill, being seen to advantage in Woodland Bay, where the thick flaggy greywackes of the middle zones are displayed. The shales at the base have yielded *Nematolites Grayi*—a form which, according to Professor Lapworth, "pre-eminently distinguishes this group throughout the Girvan region." These are the highest visible beds of the Caradoc formation on the Ardmillan shore, for the promontory at Woodland and the rocky islets at Craigskelly, north of Shalloch Mill, are formed of Llandovery strata, which are here thrown down by a prominent strike fault running parallel to the shore.

Penwhapple Glen.—The rocky gorge formed by the Penwhapple Burn affords a continuous section of the Ardwell, Whitehouse, and Barren Flagstone groups, which cover a considerable part of the plateau south of the Girvan valley between

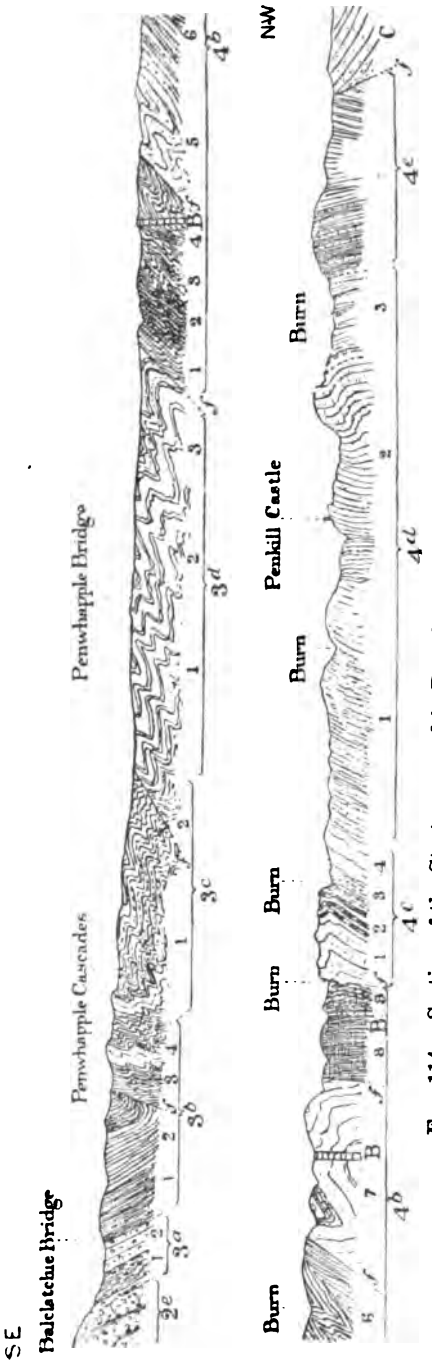


FIG. 114.—Section of the Strata exposed in Penwhapple Glen, Ayrshire (after Lapworth).

4e. Bargany group.

4d. Penkill group—
3. *Cyrtograptus Grayi* mudstones.
2. *Protovirgularia*-flags with *Monograptus exiguus.*
1. *Crossopodia*-shales.

4c. Camregan group—
4. Thick-bedded grits.
3. *Rastrites maximus*-shales.
2. Camregan, or Upper *Pentamerus*, limestone.
1. Grit and sandstone with *Rhynchonella cuneata.*

4b. Saugh Hill group—
9. Dark shales with *Monograptus Sedgwicki*, *d·c.*
8. Grey and green mudstones.
7. Thick-bedded grits.
6. Flaggy shales.
5. Grits and flagstones.
4. Grey and green shales.
3. Striped shales.
2. Dark shales with *Diplograptus confertus.* } *Diplograptus modestus* shales.
1. Mudstones and shales with *Pentameri,* }

3d. Barren flagstones—
3. Thick-bedded flags and shales with *Diplograptus truncatus.*
2. Flagstones and shales.
1. Flags, shales, and mudstones with *Nematolites Grayi.*

3c. Whitehouse beds—
2. Green and purple mudstone.
1. Shales and mudstones with *Diplograptus quadrimucronatus.*

3b. Ardwell shales—
4. Cascade grits.
3. Shales with *Dicellograpti.*
2. Grey flagstones.
1. Shales with *Climacograptus cœlatus* and *Diplograptus rugosus.*

3a. Balclatchie beds—
2. Conglomerate.
1. Mudstones, highly fossiliferous.

2e. Benan conglomerate.

B. Dolerite dykes.

f. Faults.

Millenderdale and the south slope of Hadyard Hill (Fig. 114). The richly fossiliferous mudstones and grits at Balclatchie are immediately overlain by carbonaceous shales, charged with *Climacograptus Schärenbergi*, *Lasiograptus Harknessi*, and *Cryptograptus tricornis*, forming the basal zone of the Ardwell beds. Next in order come thin iron-stained shales and flaggy shales (Knockgerran), which, though in places much contorted, dip generally to the north-west, and have yielded to Professor Lapworth: *Diplograptus foliaceus*, *D. rugosus*, *Climacograptus Schärenbergi*, *C. cælatus* var. *antiquus*, *Corynoides calycularis*, and *Dicellograptus moffatensis* (?). These lower zones contain some calcareous bands and nodules, which have furnished to Mrs. Gray, Mr. M'Kie of Knockgerran, and to Professor Lapworth the following forms: *Orthoceras angulatum*, *O. calamiteum*, *O. politum*, and *Hyalostelia girvanense*.

The shaly sub-division is followed by more flaggy beds with occasional bands of grit, and these are in turn succeeded by iron-stained shales, yielding *Dicellograptus Morrisi*, *Diplograptus rugosus*, and *Climacograptus bicornis*. Further down the stream, massive green pebbly grits which form two prominent waterfalls, are associated with dark shales and mudstones, including calcareous bands and nodules. These beds are inverted, having a persistent dip to the south-east, as if plunging underneath the graptolitic flagstones to the south. On account of the physical features to which they give rise they have been termed the Cascade-beds by Professor Lapworth, who has obtained from them the following graptolites, which place the horizon beyond doubt: *Dicellograptus Forchhammeri*, *Lasiograptus margaritatus*, *Diplograptus pristis*, *Diplograptus foliaceus*, *Climacograptus caudatus*, and *Dicranograptus ramosus* (3b^4, Fig. 114).

The members of the Whitehouse group extend down the stream from the lower waterfall for a distance of about half a mile, with a more or less persistent dip to the south-east, which is due to inversion of the beds. It is clear, however, that the strata are repeated by innumerable folds, and that the apparently considerable thickness is entirely misleading. The beds of the lower sub-division consist of dark grey shales with black seams and occasional courses of greywacke and cement-stone. From the shales Professor Lapworth obtained the following graptolites, characteristic of the *Pleurograptus linearis* zone of the Hartfell Shales, which enabled him to correlate the beds with the soft mudstones at the mouth of the Byne Hill Burn on the Ardmillan shore (3c^1):

Pleurograptus linearis (Carr.)	*Diplograptus quadrimucronatus* (Hall.)
Leptograptus flaccidus (Hall.)	
Climacograptus tubuliferus (Lapw.)	,, *foliaceus* (Murch.)
Corynoides calycularis (Nich.)	,, *truncatus* (Lapw.)

The members of the upper sub-division consist of dark blue-green mudstones, followed by a few feet of variegated mud-

stones with calcareous bands, the latter yielding some of the fossils which are found on shore in the beds of this horizon.

Further down the stream, a succession of Barren flagstones, shales, and mudstones (3d), continues for a distance of three-quarters of a mile. The strata are remarkably destitute of fossils, but near the base of the series certain green mudstones, south of the foot of Laigh Assel Burn, yield specimens of *Nematolites Grayi*. Owing to inversion, the beds have the same persistent dip to the south-east, as if they passed underneath the representatives of the Whitehouse group, but there can be little doubt that this part of the Penwhapple section displays the equivalents of the Barren Flagstone group of Woodland Bay on the Ardmillan shore. At a point about a quarter of a mile north of Penwhapple Bridge, the Barren Flagstones are truncated by a reversed fault which brings them against graptolite shales of Llandovery age (Fig. 114, 4b[1]).

Additional Exposures South of the Girvan Valley.—In addition to the two main sections of the Ardwell, Whitehouse, and Barren Flagstone groups, now described, several sections may here be noticed where one or more of these sub-divisions is well displayed on the plateau south of the Girvan valley. For our present purpose it will be sufficient to state generally the distribution of some of these sub-groups, referring at the same time to the fossiliferous localities.

In the railway cuttings between Girvan and the valley of the Stinchar to the north of Pinmore, and in various natural exposures near Meikle Letterpin, the flagstones and shales of the Ardwell group charged with their characteristic graptolites are well developed. Again, along the northern margin of the Caradoc area, on the slopes of the Fauldribban Hill, in the Piedmont Glen, on Trowier Hill, and in the various streams near Tralodden, representatives of the graptolitic flagstones appear. At most of these localities, in the dark seams associated with the flags, several of the graptolites found in the Ardwell group are obtainable. In like manner the beds of this group can be traced north-eastwards from Knockgerran to Dalamford, where they form a narrow strip, bounded on both sides by Lower Old Red Sandstone strata. At Dalamford the black shales, which are there associated with calcareous grits and sandstones, have yielded to Professor Lapworth *Climacograptus caudatus*, *Dicellograptus Forchhammeri*, *Diplograptus foliaceus*, *D. rugosus*, *Lingula*, &c., probably belonging to the horizon of the cascade-beds of the Ardwell group.

Caradoc Strata of the Craighead Inlier.—On the north side of the Girvan valley Caradoc strata not only form a large part of the "inlier" of silurian rocks, but possess there a special interest and importance from the presence of richly fossiliferous mudstones with trilobites and the starfish band at the top of the series (p. 508). These form the important zones of the highest group (Drummuck) in the Caradoc series of Girvan. That the representatives of this sub-division have not

been detected anywhere to the south of the Girvan valley, probably points to the conclusion that the original development of the Drummuck group was comparatively limited and did not extend southwards over the region that now forms the plateau between the Girvan and the Stinchar.

In the Geological Map (Sheet 14, one-inch), and in the Explanation accompanying that sheet, it was shown by Sir A. Geikie that the Caradoc strata of the Craighead inlier are arranged in the form of an anticline, which is truncated on the south side by the great strike-fault that bounds the Carboniferous strata of the Girvan valley. The trilobite mudstones of Drummuck and Lady Burn were regarded as the highest beds of Caradoc age in that limited area, being followed by the Mulloch Hill conglomerate at the base of the Llandovery strata.

The subsequent researches of Professor Lapworth revealed that the important Starfish horizon intervenes between the trilobite mudstones of Lady Burn and the Mulloch Hill conglomerate, and they further showed that the core of the arch of Caradoc strata north-east of Craighead is formed of representatives of the Barren Flagstone group. These younger Caradoc beds were believed by Professor Lapworth to be everywhere faulted against the older series at Craighead and Killochan, comprising the Arenig volcanic rocks, radiolarian cherts and mudstones, and the Craighead Limestone group.

The evidence regarding the distribution of the strata between Craighead and Quarrel Hill is to a great extent concealed by the covering of superficial deposits. Indeed, it is confined mainly to some exposures of rock near Blair and to two streams that traverse the southern limb of the anticline between the farmhouse of Farden and Quarrel Hill. The more easterly of these two burns—the one west of Quarrel Hill—gives an excellent transverse section of the representatives of this group. Near the head of the stream the strata, consisting of flagstones and shales and yielding *Nematolites Grayi*, have an easterly dip on the crest of the arch; further down, towards the little wood above Auldthorns, they are inclined to the south-east at an angle of 70°, and are composed of thin-bedded hard grey micaceous grits with bands of shale. Southwards, beyond the little wood, pale flagstones and mudstones are visible, traversed by small faults that disturb the natural sequence. Near a bend in the burn, north of the farmhouse of Auldthorns, the trilobite mudstones of the overlying Drummock group are exposed, and close to the Carboniferous boundary fault the Mulloch Hill Conglomerate crops out at the base of the Llandovery series. Similar evidence is obtained in the burn near the farmhouse of Farden, where the Barren Flagstones appear on the southern limb of the anticline. Westwards at Blair, however, the northern limb of the fold is reached for in an old quarry near that locality the flagstones, grits, and shales of this group are exposed with a northerly dip.

v. *Drummuck Group.*

The members of this important group can be traced more or less continuously as a narrow band round the outer margin of the arch of Caradoc rocks, from Drummuck on the northern limb of the fold eastwards along the course of Lady Burn, southwards round the slopes of Quarrel Hill, and westwards towards Auldthorns. The lowest beds consist of pebbly grits, sandstones, olive mudstones, and shales. They are exposed on a crag on the crest of Quarrel Hill, where they dip to the east at an angle of 30°. In the burn section to the west, as already indicated, these basal grits are underlain by the Barren Flagstones, while in the streamlets that drain the eastern slope of Quarrel Hill they are seen to be succeeded by the trilobite mudstones. The most important feature of the group, however, is the succession of blue and grey mudstones, which have become widely known owing to the abundance and perfect preservation of their trilobite fauna. Weathering with a yellow or rusty colour, and possessing a marked concretionary or nodular structure, they break under the hammer into angular fragments. They are exposed at intervals along the course of the Lady Burn for about a mile east of Drummuck Farmhouse, where their general inclination is to the north and north-west at angles varying from 20° to 30°. One of the highly fossiliferous localities occurs on the banks of the stream opposite the farmhouse of South Threave, where Mrs. Gray collected the zonal graptolite *Dicellograptus anceps*, in association with the trilobites. The subjoined list of fossils gives the forms in the collection of the Geological Survey.

Diplograptus truncatus (Lapw.)
Serpulites longissimus (Murch.)
Ampyx rostratus (Sars.)
Calymene Blumenbachi (Brong.)
,, *tuberculosa* (Salt.)
Cheirurus clavifrons (Dalm.)
,, *bimucronatus* (Murch.)
Cybele rugosa (Portl.)
Dindymene Cordai (Eth. & Nich.)
Dionide Lapworthi (Eth. & Nich.)
Illænus (Bumastus) Bowmani (Salt.)
,, *nexilis* (Salt.)
Lichas Geikiei (Eth. & Nich.)
Phacops (Acaste) Brongniarti (Portl.)
Proetus girvanensis (Eth. & Nich.)
,, *latifrons* (M'Coy.)
,, *procerus* (Eth. & Nich.)
Staurocephalus globiceps (Portl.)
Trinucleus Bucklandi (Barr.)
,, *seticornis* (His.)
,, sp.
Discina oblongata (Portl.)
Leptæna sericea (Sow.)
,, *(Plectambonites) transversalis* (Wahl.)
Lingula attenuata (Sow.)
,, *ovata* (M'Coy.)
Lingula sp.
Merista cymbula (Dav.)
Orthis (Dalmanella) elegantula (Dalm.)
,, *(Dinorthis) flabellulum* (Sow.)
,, *rustica* var. *rigida* (Dav.)
Spirifera crispa (His.)
Ctenodonta sp.
Orthonota sp.
Bellerophon acutus (Sow.)
,, *expansus* (Sow.)
,, *bilobatus* (Sow.)
,, *carinatus* (Sow.)
,, *dilatatus* (Sow.)
,, *perturbatus* (Sow.)
,, *trilobatus* (Sow.)
Holopella obsoleta (Sow.)
Loxonema sinuosum (Sow.)
,, sp.
Maclurea Logani (Salt.) (young of.)
Murchisonia pulchra (M'Coy.)
,, sp.
Pleurotomaria æquilatera (Wahl.)
,, *alata* (Wahl.)
,, *(Raphistoma) lenticularis* (Sow.)
,, *turrita* (Portl.)

Pleurotomaria sp.
Tryblidium (*Metoptoma*) sp.
Conularia elongata (Portl.)
Hyolithes (*Theca*) *corrugata* (Salt.)
,, ,, *triangularis* (Portl.)
,, ,, *vaginulus* (Salt.)
Hyolithes sp.
Orthoceras argus (Barr.)
,, *pendens* (Blake.)
,, *politum* (M'Coy.)
,, sp.

In addition to the species collected by the Survey, the following species have been obtained by Mrs. Gray.

Dicellograptus anceps (Nich.)
Diplograptus sp.
Beyrichia comma (Jones.)
,, *Klædeni* (M'Coy.)
Solenocaris solenoides (Young.)
Turrilepas sp.
Dionide sp.
Lichas laxatus (M'Coy.)
Phillipsia parabola (Barr.)
Crania sp.
Orthis mullockiensis (Dav.)
Paterula balcletchiensis (Dav.)
Strophomena grandis (Sow.)
,, *rhomboidalis* (Wilck.)
Acroculia (*Platyceras*) *haliotis* (Sow.)
Bellerophon argo (Bill.)
,, *elongatus* (Portl.) = *bilobatus* (Sow.)
,, *subdecussatus* (M'Coy.)
,, *Urei* (Flem.)
Chelodes (*Helminthochiton*) *Grayi* (Woodw.)
Euomphalus sp.
Holopea lymnæoides (Forbes.)
Loxonema elegans (M'Coy.)
Murchisonia obscura (Portl.)
Ophileta compacta (Salt.)
Platyschisma helicites (Sow.)
Raphistoma planistria var. *parva* (Hall.)
Conularia bilineata (Lindst.)
Hyolithes (*Theca*) *acutus* (Eichw.)
,, ,, *elegans* (Barr.)
,, *reversus* (Portl.)
Pterotheca sp.
Endoceras proteiforme var. *strangulatum* (Hall.)
Orthoceras angulatum (Wahl.)
,, *ludense* (Sow.)
,, *vagans* (Salt.)

The highly fossiliferous trilobite mudstones of Drummuck are succeeded near the head of Lady Burn by the Starfish beds, the position of which has been defined by Professor Lapworth and Mrs. Gray. The following description of the Starfish strata and of their outcrop in the field is given by Professor Lapworth. "Near the head of the Lady Burn, we find the purple Mulloch Hill Conglomerate crossing the little stream valley almost at right angles to the course of the burn. Over this intractable rock the waters of the stream leap in a small waterfall, at the base of which the highest known strata of the *Trinucleus* or Drummuck beds are seen, dipping steadily and conformably underneath the conglomerate at an angle of about 40°. They are soft, blue mudstones, homogeneous, thick-bedded, and more or less concretionary in structure, breaking up under the hammer into irregular and crumbling fragments. Exteriorly they are stained with rusty oxide of iron; interiorly they are pierced by frequent inosculating worm burrows, stained of a dingy red. Fossils are very rare; only an occasional brachiopod is discernible.

"At their base, however, they contain a fossiliferous band, the abundant organic remains of which fully compensate for the barren nature of the beds above. Fragments of this fossiliferous band are exposed in an old quarry opened for procuring materials for the neighbouring stone walls, in which an occasional slab from the fossil seam may even yet be detected. The

bed itself is a hard, greenish-grey sandstone, a few inches in thickness, and highly calcareous. It is almost made up of fossil remains, many being in an excellent state of preservation." *

The fossils given in the annexed list have been obtained by Mrs. Gray from this locality:

Diplograptus sp.
Halysites catenularia (Linn.)
Protocystites sp.
,, sp.
Glyptocrinus sp.
Tetraster Wyville-Thomsoni (Nich. & Eth.)
,, sp.
Solenocaris solenoides (Young.)
,, sp.
Ampyx rostratus (Sars.)
Asaphus marginalis (Portl.)
Calymene Blumenbachi (Brong.)
Phillipsia parabola (Barr.)
Staurocephalus globiceps (Wyv.-Thom.)
Trinucleus Bucklandi (Barr.)
Crania sp.
Leptæna sericea (Sow.)
,, *transversalis* (Dalm.)
Merista cymbula (Dav.)
Orthis Actoniæ (Sow.)
,, *crispa* (M'Coy.)
,, *(Dinorthis) flabellulum* (Sow.)
,, *mullockiensis* (Dav.)
,, *Rankini* (Dav.)
,, *sowerbyana* (Dav.)
,, sp.
Paterula balcletchiensis (Dav.)
Rhynchonella sp.
Skenidium Grayi (Dav.)
Strophomena (Leptæna) rhomboidalis (Wilck.)
Triplesia spiriferoides (M'Coy.)
Ctenodonta Eastnori (Murch.)
Orthonota prora (Salt.)
Pterinea Sowerbyi (M'Coy.)
Bellerophon bilobatus (Sow.)
Conularia bilineata (Lindst.)
Cyrtoceras victor (Barr.)
Orthoceras imbricatum (Wahl.)

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 619.

CHAPTER XXII.

THE GIRVAN DISTRICT—*continued.*

UPPER SILURIAN.

THE sedimentary and igneous rocks which have been discussed in the three preceding chapters belong to the Lower Silurian division of the geological scale. But they do not exhaust the varied geological history of the Girvan region during Silurian time. This interesting area includes also representatives of the Upper Silurian rocks, which, though palæontologically identifiable with the Upper Silurian formations of the rest of Scotland, nevertheless present many points of difference, which serve to indicate that the local peculiarities of sedimentation which characterised the older part of the Silurian period in the south of Ayrshire, were prolonged also into the later part.

Llandovery.

The series of rocks now to be described occurs in certain isolated areas to the north and south of the Girvan valley, (1) in the Craighead inlier, (2) in a narrow belt on the south side of the Girvan valley extending along the northern margin of the Silurian plateau from Saugh Hill by Camregan to the slopes of Hadyard Hill, (3) on the shore at Craigskelly and Woodland south of Girvan. These strata are the stratigraphical equivalents of the Birkhill Shales of the Moffat region, which are here represented by conglomerates, shelly sandstones, limestones, and shales, in which some of the Birkhill graptolite zones occur. The following sub-divisions, in descending order, have been established by Professor Lapworth in what he has termed the Newlands series of Girvan.

Newlands Series.

- *c.* Camregan Group.
  3. *Rastrites maximus* shales.
  2. Camregan limestone.
  1. *Rhynchonella* grits.
- *b.* Saugh Hill Group.
  3. *Monograptus spinigerus* shales.
  2. Saugh Hill sandstones and grits.
  1. Woodland Beds, comprising :—
     - On the south side of the Girvan valley—
       - *c.* *Diplograptus modestus* and *Monograptus gregarius* shales.
       - *b.* Woodland limestone.
       - *a.* Craigskelly conglomerate.
     - In the Craighead inlier—
       - *b.* *Monograptus gregarius* shales (Glenshalloch).
       - *a.* *Pentamerus* grits (Newlands).
- *a.* Mulloch Hill Group.
  3. Glenwells shales.
  2. Mulloch Hill sandstone.
  1. Mulloch Hill conglomerate.

Craighead Inlier.

Mulloch Hill Conglomerate.—Of the lowest subdivision of the Llandovery series, the various members of the Mulloch Hill group are typically developed in the Craighead inlier, where the order of succession is admirably clear. At the base comes a coarse conglomerate with well-rounded pebbles composed of Arenig volcanic and plutonic rocks, radiolarian chert, quartzite, quartz, and other materials. The lithological characters of the pebbles closely resemble those of the blocks in the Benan Conglomerate. The matrix, however, is sandy and of a dull purple colour, differing in these particulars from the characteristic matrix of the Benan Conglomerate. The north limb of the anticline on Quarrel Hill dips northwards at an angle of 15°, but, round the eastern and southern slopes of that eminence, the outcrop of the conglomerate is shifted by faults and is inclined to the south-east at high angles. From Quarrel Hill it can be followed westwards along the northern margin of the underlying trilobite mudstones to Drummuck and the stream near Kippery. As already indicated, various exposures of conglomerate are visible near Trochraigue, but from the presence of certain graptolites in shales embedded in it, that special deposit would seem to be partly if not wholly of Caradoc age. The fossils obtained by Professor Lapworth from the basal Llandovery conglomerate on Quarrel Hill "are principally Brachiopoda of the genera *Rhynchonella*, *Orthis*, *Leptæna*, and *Strophomena*, identical in species with those we shall find to be characteristic of the overlying Mulloch Hill sandstones, and generally distinct, considered as a group, from those that mark the immediately subjacent Drummuck mudstones. Indeed the distinction in physical features and in fossils between the soft Drummuck mudstones, with their abundant examples of *Trinucleus*, *Asaphus*, *Dionide*, *Ampyx*, and hosts of *Bellerophon*, &c., and these overlying brachiopod-sandstones is most striking, and we find here the grandest palæontological break in the entire Girvan succession. None of the genera enumerated above as characteristic of the Ardmillan group have ever yet been certainly met with above the base of this conglomerate; while the most characteristic species and genera of Trilobita, Brachiopoda, and Graptolithina of the overlying beds are equally absent from the Ardmillan series" (Quart. Jour. Geol. Soc., vol. XXXVIII., p. 622).

Mulloch Hill Sandstones.—Overlying the basal conglomerate an interesting sequence of highly fossiliferous sandstones, typically developed on Kirk or Mulloch Hill, is exposed in a series of old quarries by the side of the road that leads from North Threave to High Newlands. These strata dip towards the north or north-east at angles varying from 20° to 25°. They present distinctive lithological characters; they are soft and have a green tint, which on weathered surfaces becomes purple or brown, and they likewise break up into flaggy masses like tile-stones. They pass upwards into yellow sandstones,

followed by yellow-tinted mudstones which are seen in a small burn about 400 yards south of the farmhouse of High Newlands and yield a few brachiopods and species of *Ptilograptus*.

The fossils given in the subjoined list have been collected by the Geological Survey from the various quarries on Kirk or Mulloch Hill:

Nidulites favus (Salt.)
Favosites mullockiensis (Nich. & Eth.)
Heliolites interstinctus (Wahl.)
,, *tubulatus* (Lonsd.)
Petraia subduplicata (M'Coy.)
,, *elongata* (Phill.)
Pinacopora Grayi (Nich. & Eth.)
Streptelasma (*Petraia*) *æquisulcatum* (M'Coy.)
Fenestella sp.
Ptilodictya sp.
Calymene Blumenbachi (Brong.)
Encrinurus punctatus (Brun.)
Illænus (*Bumastus*) *Bowmani* (Salt.)
,, ,, *Maccallumi* (Salt.)
,, (*Dysplanus*) *Thomsoni* (Salt.)
Phacops Stokesi (M. Edw.)
,, sp.
Atrypa (*Leptocælia*) *hemispherica* (Sow.)
,, *reticularis* (Linn.)
Leptæna (*Christiania*) *tenuicincta* (M'Coy.)
Meristella angustifrons (M'Coy.)
Orthis calligramma (Dalm.)
,, *confinis* (Salt.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, *mullockiensis* (Dav.)
,, *rustica* (Salt.)
,, *sagittifera* (M'Coy.)
Pentamerus undatus (Sow.)
Rhynchonella cuneata (Dalm.)
,, *llandoveriana* (Dalm.)
Strophomena applanata (Salt.)
,, *compressa* (Sow.)
,, (*Rafinesquina*) *expansa* (Sow.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
,, sp.
Ctenodonta sp.
Bellerophon fastigiatus (Lindst.)
Holopella obsoleta (Sow.)
,, *tenuicincta* (M'Coy.)
Conularia Sowerbyi (Defr.)
Orthoceras sp.

Mrs. Gray has obtained the following additional species from the quarries by the roadside on Mulloch Hill:

Diplograptus sp.
Halysites catenularia (Linn.)
Heliolites parasitica (Nich. & Eth.)
Glyptocrinus sp.
Ptilodictya costellata (M'Coy.)
Retepora sp.
Acidaspis sp.
Encrinurus punctatus var. *arenaceus* (Salt.)
Lichas ambigua (Barr.)
,, *palmata* (Barr.)
Phacops (*Acaste*) *Downingæ* (Murch.)
Proetus sp.
Staurocephalus unicus (Portl.)
Atrypa scotica (M'Coy.)
Crania siluriana (Dav.)
Dinobolus Davidsoni (Salt.)
Leptæna sericea (Sow.)
Rhynchonella decemplicata (Sow.)
Strophomena antiquata (Sow.)
Ambonychia orbicularis (Conr.)
Ctenodonta sp.
Orthonota semisculata (Sow.)
,, *undata* (Sow.)
Palæarca modiolaris (Salt.)
,, *quadrata* (Salt.)
Pleurorhynchus pristis (Salt.)
Acroculia (*Platyceras*) sp.
Bellerophon dilatatus (Sow.)
,, *expansus* (Sow.)
,, *squamosus* (Lindst.)
,, *sub-decussatus* (M'Coy.)
,, *wenlockensis* (Sow.)
Euomphalus granulatus (Portl.)
,, sp.
Murchisonia cancellata (M'Coy.)
Oriostoma (*Euomphalus*) *angulatum* (Lindst.)
Pleurotomaria claustrata (Lindst.)
Trochonema sp.
Trochus Moorei (M'Coy.)
Conularia bilineata (Lindst.)
Hyolithes (*Theca*) sp.
Cyrtoceras annulatum (Hall.)
Oncoceras sp.
Orthoceras angulatum (Wahl.)
,, *imbricatum* (Wahl.)
,, *tenuicinctum* (Portl.)
Phragmoceras arcuatum (Sow.)
Trocholites (*Lituites*) *cornu-arietis* (Sow.)

The shelly sandstones of Mulloch Hill are likewise well displayed in an old quarry in a wood about 150 yards west of the farmhouse of Rough Neuk, and 400 yards north-east of High Mains Farmhouse, where they dip to the east at an angle of 40°, and fold round the anticline of Quarrel Hill. They have here furnished to the Geological Survey the fossils given in the annexed list:

Nidulites favus (Salt.)
Dictyonema sociale (Salt.)
Aulocophyllum mitratum (His.)
Favosites asper (D'Orb.)
,, *gothlandicus* (Fongt.)
,, sp.
Heliolites interstinctus (Wahl.)
,, *tubulatus* (Lonsd.)
Palæocyclus sp.
Petraia bina (Lonsd.)
,, *elongata* (Phill.)
Ptilodictya costellata (M'Coy.)
,, sp.
Glyptocrinus basalis (M'Coy.)
Calymene Blumenbachi (Brong.)
Atrypa reticularis (Linn.)
Leptæna (Christiania) tenuicincta (M'Coy.)
Leptocœlia (Atrypa) hemispherica (Sow.)
Meristella angustifrons (M'Coy.)
Orthis calligramma (Dalm.)
,, *reversa* (Salt.)
Rhynchonella llandoveriana (Dav.)
Orthonota simplex (Portl.)
Pterinea hyans (M'Coy.)
Bellerophon dilatatus (Sow.)
Macrocheilus elongatus (Portl.)
Murchisonia cancellata (Sow.)
,, *elongata* (Portl.)
Gomphoceras sp.

The following additional species have been obtained by Mrs. Gray from the Rough Neuk Quarry.

Heliolites parasitica (Nich. & Eth.)
Pinacopora Grayi (Nich. & Eth.)
Streptelasma (Petraia) æquisulcatum (M'Coy.)
Tentaculites anglicus (Salt.)
Fenestella sp.
Retepora sp.
Encrinurus punctatus var. *arenaceus* (Salt.)
Illænus (Dysplanus) Thomsoni (Salt.)
Lichas ambigua (Barr.)
,, *palmata* (Barr.)
Phacops (Acaste) Downingæ (Murch.)
Staurocephalus unicus (Portl.)
Crania siluriana (Dav.)
Dinobolus Davidsoni (Salt.)
Leptæna sericea (Sow.)
Lingula ovata (M'Coy.)
Orbiculoidea Forbesi (Dav.)
Orthis (Dalmanella) elegantula (Dalm.)
,, *mullockiensis* (Dav.)
,, *rustica* (Sow.)
,, *sagittifera* (M'Coy.)
Rhynchonella cuneata (Salt.)
Strophomena antiquata (Sow.)
,, *(Rafinesquina expansa* (Sow.)
Strophomena (Leptæna) rhomboidalis (Wilck.)
Ambonychia orbicularis (Conr.)
Ctenodonta sp.
Orthonota semisulcata (Sow.)
,, *undata* (Sow.)
Palæarca modiolaris (Salt.)
,, *quadrata* (Salt.)
Pleurorhynchus pristis (Salt.)
Bellerophon dilatatus (Sow.)
,, *subdecussatus* (M'Coy.)
,, *wenlockensis* (Sow.)
Euomphalus granulatus (Portl.)
Holopella obsoleta (Sow.)
,, *tenuicincta* (M'Coy.)
Murchisonia cancellata (M'Coy.)
Oriostoma angulatum (Lindst.)
Pleurotomaria claustrata (Lindst.)
Trochonema sp.
Trochus Moorei (M'Coy.)
Conularia bilineata (Lindst.)
Hyolithes sp.
Cyrtoceras annulatum (Hall.)
Orthoceras imbricatum (Wahl.)
,, *tenuicinctum* (Portl.)
Phragmoceras arcuatum (Sow.)
Trocholites (Lituites) cornu-arietis (Sow.)

From Rough Neuk the shelly sandstones can be traced westwards along the south limb of the arch in the direction of Auldthorns, where they yield in abundance the fossils of this horizon.

Glenwells Shales.—The strata following next in order —the Glenwells Shales—are seen to advantage in the Glenwells Burn, which, rising on the east slope of Kirk or Mulloch Hill, enters the Carboniferous basin at the cottage of Glenwells, half a mile east of High Mains Farmhouse. Owing to the covering of superficial deposits the section in this stream is not continuous, but there can be no doubt of the super-position of these shales to the Rough Neuk Sandstones, for near the head of the burn shelly sandstones belonging to the latter horizon are visible, and can be traced more or less continuously round the slope towards Rough Neuk Quarry. Further down the stream, below a blank in the section, green and blue mudstones, which dip towards the E.S.E. at an angle of 40°, are exposed in the bed of the burn for some distance. They have a distinct concretionary or nodular structure, and break with a conchoidal fracture. Fossils are not readily found in them, but certain striped shales in them yield a few graptolites, which are valuable in defining the horizon relatively to the Moffat sequence. Professor Lapworth here obtained *Diplograptus acuminatus*, *Climacograptus scalaris*, and *Monograptus tenuis* (?), while the following forms were collected by the Geological Survey: *Climacograptus normalis*, *Diplograptus*, *Avicula Danbyi*, and *Orthoceras*.

Saugh Hill Group (Craighead Inlier).—The relations of the graptolitic mudstones last mentioned to the succeeding strata are not visible, owing to a concealed space of nearly fifty yards, beyond which, above the cottage of Glenwells, a group of strata appears, on the horizon of the *Pentamerus*-grits of Newlands.

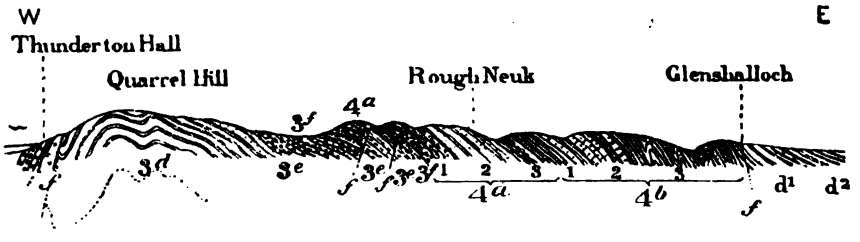


FIG. 115.—Section across Quarrel Hill and Rough Neuk from Thunderton Hall to Glenshalloch.

4b. Saugh Hill Group { 3. Glenshalloch shales (*Monograptus gregarius*-zone). 2. *Pentamerus* grits. 1. Pale shale with *Diplograptus acuminatus*.

4a. Mulloch Hill Group { 3. *Ptilograptus* shales. 2. Mulloch Hill sandstone. 1. Mulloch Hill conglomerate.

3f. Starfish bed. 3e. Drummuck mudstones. 3d. Barren flagstones.

In the extreme north-east corner of the Craighead inlier, where the Llandovery strata disappear under the covering of Lower Old Red Sandstone to the north, and where they are

truncated by the powerful fault at the margin of the Carboniferous rocks of the Girvan valley, two subdivisions are developed, viz.: the *Pentamerus*-grits of Newlands and the graptolite shales of Glenshalloch. These shales belong to the horizon of the *Monograptus gregarius* zone of the Birkhill Shales of the Moffat region. Unfortunately, no continuous section shows their relations to the Mulloch Hill Sandstones and Glenwells Shales, but though their relative position can only be determined by means of isolated exposures, it is clear that they form the outermost and highest zones of the Llandovery series in the Craighead inlier.

Pentamerus-Grits of Newlands.—The lowest visible beds are met with in the Glenwells Burn a few yards above the cottage, where they consist of pale yellow sandstones and flags with bands of conglomerate. The sandstones are more or less calcareous, and alternate with pebbly or conglomeratic beds. Northwards from this locality, along the strike, these strata appear close to the farmhouse of Newlands, where grey grit is seen in the burn west of the house, and yellow sandstones further down the stream. The best exposure of fossiliferous bands, however, is to be found in the streamlet in a narrow belt of plantation about 250 yards north-east of Newlands, where pale yellow sandstones and calcareous flags appear immediately to the east of an old quarry. Here fossils occur in considerable abundance, and the following forms have been collected by the Geological Survey:

Calymene Blumenbachi (Brong.)
Cheirurus bimucronatus (Murch.)
Orthis (*Dinorthis*) *flabellulum* (Sow.)
Pentamerus oblongus (Sow.)
Pentamerus undatus (Sow.)
Rhynchonella borealis ? (Schl.)
Stricklandinia lens (Sow.)
Holopea concinna (M'Coy.)

In addition to the foregoing forms, Mrs. Gray has obtained from the *Pentamerus* beds at Newlands the fossils enumerated in the annexed list:

Ischadites sp.
Halysites catenularia (Linn.)
Pinacopora Grayi (Nich. & Eth.)
Glyptocrinus sp.
Fenestella sp.
Turrilepas sp.
Cythere sp.
Acidaspis sp.
Bronteus Andersoni (Nich. & Eth.)
Encrinurus punctatus var. *arenaceus* (Salt.)
Lichas ambigua (Barr.)
Phacops Stokesi (M. Edw.)
Staurocephalus globiceps (Wyv.-Thom.)
Orthis sowerbyana (Dav.)
Crania llandoveriana (Dav.)
Crania (*Pholidops*) *implicata* (Sow.)
Rhynchonella sp.
Strophomena applanata (Salt.)
,, *corrugatella* (Dav.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
Orthonota undata (Sow.)
Bellerophon sp.
Cyrtolites euryomphalus (Lindst.)
Pleurotomaria (*Euomphalus*) *qualteriata* (Schl.)
Metoptoma sp.
Platyceras cornutum (His.)
Pterotheca sp.
Oncoceras sp.
Orthoceras angulatum (Wahl.)

Glenshalloch Shales.—In the streams to the south-east of Newlands Farmhouse, near the old ruins of Glenshalloch, the highest Llandovery strata of the Craighead inlier have yielded an assemblage of graptolites characteristic of the *Monograptus gregarius* zone. Perhaps the best section is that exposed in the west branch of the Baldrennan Burn, that enters the Carboniferous basin near Pathhead, where the rocks occupy the stream course for a space of 150 yards. The lowest visible beds consist of flagstones which pass upwards into flaggy grey shales, while at the lower or east end of the section black and grey striped shales appear. The strata dip at a high angle to the south-east, but are sometimes vertical and highly folded. The black seams yield graptolites sparingly; the forms given in the following list have been collected from this locality by the Geological Survey:

Climacograptus normalis (Lapw.)
Diplograptus tamariscus (Nich.)
Petalograptus folium (His.)
Monograptus attenuatus (Hopk.)
,, *gregarius* (Lapw.)
Monograptus tenuis (Portl.)
Rastrites peregrinus (Barr.)
Retiolites sp.
Pterinea tenuistriata (M'Coy.)
Orthoceras politum (M'Coy.)

From these striped shales Professor Lapworth obtained the following additional graptolites: *Monograptus argutus*, *M. crenularis*, *M. fimbriatus*, and *M. leptotheca*.

The evidence adduced in the foregoing paragraphs regarding the sequence of Llandovery strata in the Craighead inlier may thus be tabulated in descending order:

Saugh Hill Group.	2. Striped shales of Baldrennan and Glenshalloch (*Monograptus gregarius* zone).
	1. *Pentamerus* grits and sandstones of Newlands.
Mulloch Hill Group.	3. Glenwells mudstones and shales (*Diplograptus acuminatus* zone).
	2. Shelly sandstones of Mulloch Hill and Rough Neuk.
	1. Mulloch Hill conglomerate.

District of Penwhapple Glen, Saugh Hill, and Camregan.

The sequence and physical relations of the Llandovery strata on the south side of the Girvan valley present serious difficulties to the investigator, owing to the prevalence of inverted folding and the existence of strike faults. Indeed the persistent isoclinal folding of the Llandovery grits and shales on Saugh Hill and in Penwhapple Glen, whereby these beds appear to dip beneath the Barren Flagstones and Ardwell beds lying to the south, led Murchison and subsequent investigators to the erroneous belief that the Saugh Hill grits belong to a lower geological horizon than the graptolite-bearing flags (Caradoc) of the Ardmillan series. The palæontological difficulties involved in this reading of the section were ultimately solved by Professor Lapworth when he identified in Penwhapple Glen three prominent graptolite zones of the Birkhill division of the Moffat sequence,

viz.: (1) *Monograptus gregarius*, (2) *M. spinigerus*, (3) *Rastrites maximus*, which here occur in inverted order among the coarse grits, shales, and limestones with which they are associated. He further proved that the belt of Llandovery strata, extending from the Saugh Hill, by Penwhapple Glen, to the slopes of Hadyard Hill, are separated by a strike fault from the Barren Flagstones of Caradoc age to the south. At first one might be apt to suppose that this fault must be of considerable magnitude owing to the absence of the Mulloch Hill group in the Llandovery areas south of the Girvan valley, but the same observer has adduced evidence, which will be referred to presently, from the shore at Shalloch Forge, south of Girvan, pointing to an unconformability between the Craigskelly conglomerate (the local base of the Saugh Hill group) and the underlying Barren Flagstones of Caradoc age. If this unconformability be granted, the strike fault, though it disturbs the natural sequence, will be seen to be of no great amount for the lowest well-defined zone of Llandovery age in Penwhapple Glen is that of the *Diplograptus modestus* shales (*Monograptus gregarius*), which are not separated by any great thickness of strata from the Craigskelly Conglomerate (Figs. 112, 114).

Diplograptus confertus (modestus)-Shales.*—Immediately to the north of the strike-fault that forms the southern boundary of the Llandovery series, some green and grey calcareous flags and shales in Penwhapple Glen have yielded to Professor Lapworth *Pentamerus* sp. These strata are succeeded northwards by black mudstones and shales charged with graptolites, of which the following forms have been collected by the Geological Survey, viz.: *Monograptus gregarius*, *M. crenularis*, *Diplograptus confertus (modestus)*, *D. tamariscus*, *D. Hughesi*, *Petalograptus folium*, and *Dimorphograptus Swanstoni*. In addition to these species, Professor Lapworth records *Monograptus leptotheca*, and *Climacograptus normalis*. These graptolitic mudstones pass upwards into the thick mass of grey shales which form the dominant lithological feature of the zone; some of the dark seams interleaved in them yield similar graptolites, together with orthoceratites. Like the Barren Flagstones to the south, the beds of this zone have a persistent inverted dip to the south-east.

Saugh Hill Grits.—Northwards, from the shales last mentioned, massive grey grits in inverted order contain small quartz pebbles, weather with a yellow tint, and are remarkably destitute of fossils. They are associated with flagstones, and at the point where a small tributary joins the Penwhapple Burn from the west, shattery grey shales appear in the heart of the grit series.

Monograptus Sedgwicki-Mudstones (*M. spinigerus*-Zone).—These pebbly grits are followed northwards by a prominent zone of grey and black mudstones and shales, which

* *Diplograptus modestus* (Lapw.) = *Diplograptus (Dimorphograptus) confertus* (Nich.).

is well displayed at a bend in the Penwhapple Glen, about 400 yards south of the foot of Penkill Burn. The lower or southern half of this band is formed of greyish-green shales, yielding no fossils, while the northern portion furnishes a characteristic assemblage of graptolites. The graptolitic part is thus described by Professor Lapworth*: "It consists essentially of soft shaly mudstones, containing a large proportion of carbonaceous matter, and impregnated with sulphate of iron. The entire group is stained of a deep iron-shot colour, and is so excessively crushed and contorted that the bedding can only be made out with the utmost difficulty. Calcareous matter is occasionally present in notable quantity, and large nodular concretions are abundant in the steep cliffs of the rock which overhang the right bank of the stream. Graptolites are abundant, but are most difficult of extraction in consequence of the crushing to which these beds have been subjected, while fragments of crustacea and orthoceratites are occasionally seen." These fossiliferous mudstones and shales yielded the following forms to the Geological Survey: *Monograptus Sedgwicki*, *M. spinigerus*, *Petalograptus ovatus*, *Rastrites peregrinus*, and *Lingula brevis*.

Professor Lapworth obtained the additional forms given in the annexed list:

Monograptus tenuis (Portl.)	*Diplograptus Hughesi* (Nich.)
,, *attenuatus* (Hopk.)	,, *tamariscus* (Nich.)
,, *Hisingeri* (Carr.)	*Climacograptus normalis* (Lapw.)
,, *intermedius* (Carr.)	*Petalograptus folium* (His.)
,, *spiralis* (His.)	,, *palmæus* (Barr.)

Camregan Grits and Limestone.—The black fossiliferous mudstones and shales just described are succeeded northwards by an important group of strata, comprising grits, impure limestone, shales, and mudstones, which have yielded a large series of organic remains of an undoubted Llandovery facies. These strata are well seen below Camregan Plantation on the east bank of the rocky gorge formed by the Penwhapple Burn, where they are nearly vertical or inclined at high angles to the south-east. The beds in contact with the crushed mudstones of the *Monograptus Sedgwicki* zone consist of massive grits and flags (*Rhynchonella*-grits), which extend for several yards down stream. They resemble the Saugh Hill grits in lithological characters, and, like them, are comparatively barren, except near the base, where Professor Lapworth found in them "casts of *Rhynchonella*, associated with rarer examples of *Orthis* and *Strophomena*." Next come in inverted order nodular calcareous flagstones, which merge into impure highly fossiliferous limestones (Camregan Limestone) that dip to the S.S.E. at an angle of about 70°. These are followed by blue calcareous shales and mudstones, which are likewise fossiliferous, many of the organisms occurring

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 633.

in a fine state of preservation. The species given in the annexed list were obtained from these strata by the Geological Survey:

Ischadites antiquus (Salt.)
Calostylis Lindströmi (Nich. & Eth.)
Halysites catenularia (Linn.)
Petraia sp.
Ptilodictya dichotoma (Portl.)
Bronteus Andersoni (Eth. & Nich.)
Calymene Blumenbachi (Brong.)
Cheirurus trispinosus (Young.)
Encrinurus punctatus (Brunn.)
Illænus (*Dysplanus*) *æmulus* (Salt.)
,, ,, *Thomsoni* (Salt.)
,, (*Bumastus*) *Bowmani* (Brong.)
,, *nexilis* (Salt.)
,, sp.
Phacops Stokesi (M. Edw.)
Atrypa reticularis (Linn.)
Glassia (*Athyris*) *obovata* (Sow.)
Leptæna (*Plectambonites*) *transversalis* (Dalm.)
Lingula Symondsi (Salt.)
Orthis calligramma (Dalm.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, *polygramma* (Dav.)
Pentamerus globosus (Sow.)
,, *oblongus* (Sow.)
,, *rotundus* (Sow.)
,, *undatus* (Sow.)
Crania (*Pholidops*) *implicata* (Dav.)
Spirifera plicatella (Linn.)
Strophomena antiquata (Sow.)
,, *applanata* (Salt.)
,, (*Rafinesquina*) *expansa* (Sow.)
Triplesia incerta (Dav.)
Bellerophon bilobatus (Sow.)

The following additional forms are recorded by Mrs. Gray from the same fossiliferous horizon:

Chondrites sp.
Monograptus galaensis (Lapw.)
,, *Hisingeri* (Carr.)
,, *spiralis* (Geinitz.)
Dictyonema (*Fenestella*) *assimile* (Lonsd.)
Acidaspis bispinosus (M'Coy.)
Encrinurus punctatus var. *arenaceus* (Salt.)
Illænus Murchisoni (Salt.)
,, *Rosenbergi* (Eichw.)
Atrypa imbricata (Sow.)
Crania sp.
Cyrtia exporrecta (Wahl.)
Leptæna sericea (Sow.)
Orthis polygramma var. *pentlandica* (Dav.)
Pentamerus galeatus (Sow.)
Strophomena Walmstedti (Lindst.)
Ambonychia bellistriata (Hall.)
Avicula sp.
Cardiola striata (Sow.)
Goniophora cymbæformis (Sow.)
Mytilus mytilimeris (Conr.)
,, *semirugatus* (Portl.)
Orthonota sp.
Bellerophon expansus (Sow.)
,, sp.
Cyclonema sp.
Euomphalus sp.
Pleurotomaria sp.
Hyolithes sp.
Pterotheca sp.
Cyrtoceras compressum (Sow.)
Gomphoceras sp.
Orthoceras angulatum (Wahl.)
,, *bacchus* (Barr.)
,, *fusiforme* (Hall.)
,, *imbricatum* (Wahl.)
,, *multicinctum* (Hall.)
,, *primævum* (Forbes.)
Poterioceras sp.

Rastrites maximus-Shales.—The *Pentamerus* limestone and shales of Camregan are immediately followed by purple and green mudstones, which, with the exception of annelid tracks, are remarkably destitute of fossils. They contain, however, a thin seam of silky carbonaceous shale, which is well seen in the bed of the Penwhapple Burn and in the streamlet on the west side of a gorge, where Professor Lapworth obtained the following characteristic suite of graptolites, together with occasional examples of phyllopodous crustacea:

Rastrites maximus (Carr.)
Monograptus turriculatus (Barr.)
,, *crassus* (Lapw.)
,, *Hisingeri* (Carr.)
Monograptus runcinatus (Lapw.)
Petalograptus palmæus (Carr.)
Peltocaris aptychoides (Salt.)

The observations of the same geologist further show that the purple mudstones containing the seam of carbonaceous shale, with *Rastrites maximus* and some of its associates, are succeeded northwards by massive grits, which are regarded by him as the highest sub-division of the Camregan group.

Sections East of Penwhapple Glen.

Besides the typical section in Penwhapple Glen of Llandovery strata, ranging from the *Diplograptus confertus (modestus)* shales to the *Rastrites maximus* zone, the prolongations of the same beds are to be seen both to the east and to the west of that line of section.

The Geological Map (Sheet 8) shows that the fault which forms the southern boundary of the Llandovery strata in Penwhapple Glen, and separates them from the Barren Flagstones of Caradoc age to the south, can be traced eastwards to the slope of Hadyard Hill and westwards along the south flank of Saugh Hill. Though, in Penwhapple Glen this dislocation is probably of no great magnitude, yet eastwards to the slope of Hadyard Hill it evidently increases in amount, for in that direction the members of the Camregan group are brought into contact with the Caradoc Rocks to the south. In other words, the strata associated with the *Diplograptus confertus* shales and the Saugh Hill grits have there been thrown out by this east and west fault.

Owing partly to this dislocation and partly to the covering of superficial deposits, the Llandovery beds underlying the Camregan group are almost wholly concealed from view in the area east of Penwhapple Glen. Several good sections, of the Camregan beds in that region, however, have supplied large and characteristic suites of organic remains. The first of these is met with near the head of the southern branch of the Penkill Burn—a tributary which joins the Penwhapple Burn from the east. This exposure is merely the easterly prolongation of the outcrop in Penwhapple Glen, though only a portion of the sequence is visible, which here consists of calcareous bands and yellow grits. Situated close to the road leading to the village of Barr from Girvan, the fossiliferous zones are easy of access, and the various brachiopods, trilobites, and other organisms characteristic of the *Pentamerus* limestone of Camregan may be readily obtained.

About a mile still further east, at the head of Bargany Pond Burn, which rises on the western slope of Hadyard Hill, near Littlelane, another good outcrop is to be seen of the Camregan group, composed here of grey clayey shales or mudstones with calcareous ribs and bands of grit, which dip towards the south at high angles. On the weathered surfaces of the limestone, crinoids and other organic remains appear, while the grey clayey shales yield well-preserved trilobites belonging to the genera

Encrinurus, Phacops, &c. A careful search at this locality furnished the following forms to the Geological Survey:

Glyptocrinus sp.
Crinoid stems.
Myrianites sp.
Beyrichia Klædeni (M'Coy.)
Acidaspis sp.
Cheirurus bimucronatus (Murch.)
Encrinurus punctatus var. *arenaceus* (Salt.)
Illænus (*Bumastus*) *barriensis* (Murch.)
,, ,, *Bowmani* (Salt.)
Phacops Stokesi (M. Edw.)
Proetus girvanensis (Eth. & Nich.)
Cyrtia exporrecta (Wahl.)
Discina perrugata (M'Coy.)
,, *rugata* (Sow.)
Leptæna sericea (Sow.)
,, (*Plectambonites*) *transversalis* (Wahl.)
Orthis balcletchiensis (Dav.)
Orthis (*Bilobites*) *biloba* (Linn.)
,, (*Dalmanella*) *elegantula* (Dalm.)
Pentamerus globosus (Sow.)
,, *rotundus* (Sow.)
,, *undatus* (Sow.)
Crania (*Pholidops*) *implicata* (Dav.)
Spirifera crispa (His.)
,, *plicatella* var. *radiata* (Sow.)
Stricklandinia lens (Sow.)
Strophomena antiquata (Sow.)
,, *applanata* (Salt.)
,, (*Rafinesquina*) *deltoidea* (Conr.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
,, *undata* (M'Coy.)
Whitfieldia (*Meristella*) *tumida* (Dalm.)
Bellerophon squamosus (Lindst.)
Pleurotomaria (*Euomphalus*) *qualteriata* (Schl.)
Orthoceras fimbriatum (Sow.)
,, *Grayi* (Blake.)
,, sp.

Mrs. Gray has collected from the same locality the additional forms given in the annexed list:

Ptilodictya dichotoma (Portl.)
Beyrichia Klædeni var. *scotica* (Jones & Holl)
Ulrichia Grayæ (Jones.)
Bronteus Andersoni (N. & E.)
Harpes sp.
Illænus nexilis (Salt.)
Staurocephalus sp.
Atrypa imbricata (Sow.)
Lingula Symondsi (Salt.)
Nucleospira pisum (Sow.)
Orthis sowerbyana (Dav.)
Triplesia incerta (Dav.)
Mytilus semirugatus (Portl.)
Pleurotomaria sp.
Orthoceras Bacchus (Barr.)

About thirty yards down the stream to the north of this outcrop of limestone and shales, grey and purple mudstones with dark carbonaceous seams appear, from which Professor Lapworth obtained well-preserved specimens of

Rastrites maximus (Carr.)
Monograptus crassus (Lapw.)
,, *turriculatus* (Barr.)
Monograptus Hisingeri (Barr.)
Diplograptus palmæus (Barr.)
Peltocaris aptychoides (Salt.)

It thus appears that the *Rastrites maximus*-mudstones have here the same relative stratigraphical position with reference to the Camregan Limestone as in the typical section in Penwhapple Glen. But owing to the covering of drift deposits the relations of these sub-divisions of the Camregan group to the underlying and overlying strata are not apparent. Nevertheless it is possible to fix approximately the position of the fault that forms the southern boundary of the Llandovery Rocks, for in a quarry about 300 yards to the south of the outcrops just referred to in

Bargany Burn, dark grit and greenish greywacke furnish specimens of *Diplograptus truncatus* and other Upper Hartfell forms (Upper Caradoc).

Sections West of Penwhapple Glen.

Proceeding now to deal with the westerly prolongations of the Llandovery (Birkhill) strata visible in Penwhapple Glen, we may note that various excellent exposures of the different subdivisions occur on Saugh Hill, likewise near Camregan Wood and in the adjoining streams. The shales associated with the *Diplograptus confertus* (*modestus*) band are visible near the foot of the streamlet that flows eastwards between Tralorg and Camregan Hills, but westwards they are truncated and cut out by the Saugh Hill fault as far as the south-west slope of that eminence. From dark seams at this latter locality Professor Lapworth records the following characteristic graptolites:

Diplograptus tamariscus (Nich.)	*Monograptus cyphus* (Lapw.)
,, *modestus* (Lapw.)	,, *gregarius* (Lapw.)
Climacograptus normalis (Lapw.)	,, *tenuis* (Portl.)

The coarse yellow grits (Saugh Hill Grits) occupying an intermediate position between the *Diplograptus confertus (modestus)*-shales and the *Monograptus Sedgwicki*-mudstones form a conspicuous feature on the plateau to the west of Penwhapple Glen, for they may be traced almost continuously from that stream along the ridge of Camregan Hill to the crest of Saugh Hill, where they form a belt nearly 200 yards in width. From the Geological Map (Sheet 8) it will be seen that the prominent development of this zone on Saugh Hill is due to folding. The strata, which may there be studied in many quarries and natural exposures, have generally an inverted dip to the S.S.E., and consist of flaggy and massive yellow grits with bands of conglomerate and breccia, containing angular fragments of grits, shales, and other materials.

The overlying *Monograptus Sedgwicki*-mudstones cannot be traced for any distance, owing to the covering of drift, but they do appear on the northern slopes of Saugh Hill. At a locality not far to the west of the fence which forms the boundary between the estates of Bargany and Killochan, these mudstones supplied Professor Lapworth with the following forms:

Rastrites hybridus (Lapw.)	*Diplograptus palmæus* (Barr.)
Monograptus Sedgwicki (Portl.)	,, *tamariscus* (Nich.)
,, *spiralis* (Gein.)	*Climacograptus normalis* (Lapw.)
,, *lobiferus* (M'Coy.)	

In like manner, the fossiliferous grits of the Camregan group that overlie the *Monograptus Sedgwicki* mudstones can be traced westwards to the south-east corner of Camregan Wood, where they appear in a quarry, charged with many of the characteristic

fossils of that sub-division. Regarding these beds, Professor Lapworth remarks that "they are crowded with casts of brachiopoda, which are so abundant in certain seams as irresistibly to recall to mind the wonderfully prolific shelly sandstones of Mulloch Hill, on the north of the Girvan valley. The beds, too, have the same coarse sandy texture, calcareous and gritty composition, and more or less flaggy fracture." From the sandstones and grits in this quarry the following fossils have been obtained:

Cheirurus sp.
Encrinurus punctatus (Brun.)
Phacops Stokesi (M. Edw.)
Leptocœlia (*Atrypa*) *hemispherica* (Sow.)
Pentamerus oblongus (Sow.)
Rhynchonella llandoveriana (Dav.)
Pterinea sp.
Platyceras cornutum (His.)

The Camregan group is likewise seen in a burn at the west end of Camregan Wood, where it has supplied some of its characteristic fossils, and still further west at the head of Cuddystone Burn, from which locality Mrs. Gray records the species given in the annexed list:

Calymene Blumenbachi (Brong.)
Leptæna segmentum (Ang.)
Orthis rustica (Sow.)
Pentamerus oblongus (Sow.)
,, *undatus* (Sow.)
Strophomena applanata (Salt.)
Strophomena Walmstedti (Lindst.)
,, *Waltoni* (Dav.)
Orthonota sp.
Cyclonema sp.
Euomphalus sp.
Orthoceras imbricatum (Wahl.)

Shalloch and Woodland, South of Girvan.

The only remaining patches of Llandovery strata (Birkhill or Newlands series, Lapworth) south of the Girvan valley which have yet to be described are to be found on the shore immediately to the south of Girvan, where they form a series of reefs near high-water level. Though disconnected and available for study only when the tide is favourable, the strata are nevertheless of considerable interest, both on lithological and palæontological grounds. At these localities, coarse conglomerates, which Professor Lapworth believes to rest unconformably on the underlying Caradoc Rocks, are associated with grits, shales, and coralline limestones, which, in virtue of their fossil contents, can be referred to the lower portion of the Saugh Hill group. The physical relations of the beds forming these rocky islets have been studied by Professor Lapworth, from whose descriptions the following details are taken.*

The first of these exposures occurs on the beach at Shalloch, about half a mile south of Girvan, where the strata strike inland from the shore and dip towards the north and N.N.E. The prominent feature in this section is the ridge of conglomerate named the Horse Rock. It measures about fifty feet in thick-

* Quart. Jour. Geol. Soc., vol. xxxviii., p. 638, *et seq.*

ness, and rests with a slight unconformability on green flagstones and shales to the south, which can be seen only at low tide. While destitute of organic remains, these flagstones and shales resemble lithologically the Barren Flagstones of the Ardmillan series (Caradoc), and in all likelihood belong to that sub-division of the Silurian system. The overlying conglomerate, which is interbedded with bands of green granular grit, has a green matrix containing well-rounded blocks of diabase-lava, acid and basic intrusive rocks, chert, shale, greywacke, quartzite, mica-schist, and other materials. Indeed, except for its highly indurated character and the presence of the quartzite pebbles, the rock is similar to the characteristic conglomerate of Benan. A few yards to the north the sandy beach lays open some limited outcrops of calcareous flagstone or impure limestone, from which Professor Lapworth obtained specimens of *Alveolites Labechei*, *Favosites gothlandica*, and other corals, together with numerous casts of *Pentamerus oblongus* and other brachiopods. Next in order come dark blue and grey flaggy shales with thin carbonaceous seams, traceable across the beach, and yielding graptolites of the following species: *Diplograptus* (*confertus*) *modestus*, *Climacograptus normalis*, *Monograptus tenuis*, and *M. cyphus*, together with forms of *Dictyonema* and *Orthoceras*—an assemblage similar to that found in the *Diplograptus confertus* (*modestus*) shales in the typical section of Penwhapple Glen.

Above these graptolite-bearing shales come conglomeratic sandstones with numerous white quartz-pebbles, the lowest beds of which contain angular fragments of the underlying shales, as if the junction between the sandstones and shales had originally been an unconformable one, though this relationship is now masked to some extent by an intervening fault. The phenomena presented by these rocks at their line of contact are thus described by Professor Lapworth: "The lowest visible zone of the sandstone conglomerate is filled with pieces of the same striped shales, which are surrounded and buried up by the coarser pebbly rock, as if they had projected from the sea-floor at the time of the formation of the sandstone, and had been enveloped and buried by the latter, being deposited around and above them. Thus it is highly probable that the conglomeratic sandstones, which now dip generally with the underlying beds, were originally somewhat discordant with them, and that their present steep dip is owing to the intercalary fault we have referred to. This fault, however, while it has permitted these overlying beds to be crushed into a general correspondence in inclination with the underlying strata, has not actually allowed of their removal far from their original position, the angular fragments included in the sandstones being previously derived from the striped shales with which they are still in contact."

From these details it may be inferred that some of the zones near Shalloch are the equivalents of part of the lower portion of the Saugh Hill group; for example, the graptolite-bearing shales are evidently the counterpart of the *Diplograptus*

confertus (*modestus*) shales of Penwhapple Glen, and the overlying quartz-conglomerate and sandstones correspond to similar strata at the base of the Saugh Hill Grits, while the coarser conglomerate of the Horse Rock apparently occupies a lower geological horizon than any of the Llandovery beds exposed in the Penwhapple Glen or Saugh Hill sections.

Craigskelly.—Not far to the south-west of the Horse Rock, coarse conglomerate reappears, with a north-east and south-west strike, in a rocky islet named Craigskelly, where it is associated with grits, weathering with a yellow tint and yielding fragments of *Strophomena grandis*, *Atrypa reticularis*, *A. hemisphærica*, and *Dictyonema*.

Woodland Point.—About three-quarters of a mile along the shore to the south of Craigskelly, these Lower Llandovery Grits are again visible in certain reefs, named the Scart Rocks, in Woodland Bay, and also at Woodland Point. At this latter locality they are associated with calcareous bands, which have yielded a large number of organic remains that clearly define the geological horizon of the beds. The rocky headland is formed of massive grits, weathering with a yellow tint and nearly vertical, and having a north-east strike in the direction of the Scart Rocks and Craigskelly; indeed, there can be little doubt that the grits visible at these various exposures are merely the prolongations of the same band.

These pebbly grits and conglomerates are succeeded along their south-east margin by highly fossiliferous strata, which protrude through the sandy beach, and are available for study only at low tide. First a few feet of green flaggy shales with thin carbonaceous and calcareous seams, are probably faulted against the conglomeratic sandstones; their geological horizon, however, is placed beyond doubt by the graptolites which have been obtained from them, viz.: *Diplograptus confertus* (*modestus*), *Climacograptus normalis*, *Monograptus tenuis*, *M. gregarius*, and *M. leptotheca*. These strata are succeeded by soft green shales containing specimens of *Strophomena grandis*, *Atrypa reticularis*, *A. imbricata*, *Orthis elegantula*, &c., and then by about thirty feet of calcareous flagstones or limestones, crowded with organic remains, including *Pentamerus oblongus* and *Stricklandinia lens*. The following fossils have been collected from this horizon by the Geological Survey:

Favosites mullochensis (Nich. & Eth.)
Pinacopora Andersoni (Nich. & Eth.)
Fenestella sp.
Bronteus Andersoni (Eth. & Nich.)
Cheirurus bimucronatus (Murch.)
Encrinurus punctatus (Brün.)
Illænus sp.
Phacops (*Acaste*) *Downingæ* (Murch.)
Staurocephalus unicus (Wyv.-Thom.)
Atrypa imbricata (Sow.)
,, *reticularis* (Linn.)
Crania siluriana (Dav.)
Leptæna (*Plectambonites*) *quinquecostata* (M'Coy.)
,, *segmentum* (Ang.)
,, (*Plectambonites*) *transversalis* (Wahl.)
,, ,, ,, var.
Lingula Symondsi (Salt.)
Orbiculoidea Forbesi (Dav.)
Orthis (*Bilobites*) *biloba* (Linn.)
,, *calligramma* var. *plicata* (Sow.)
,, (*Dalmanella*) *elegantula* (Dalm.)

Orthis rustica var. *rigida* (Dav.)
Pentamerus undatus (Sow.)
Pholidops (*Crania*) *implicata* (Dav.)
Skenidium woodlandiensis (Dav.)
Stricklandinia lens (Sow.)
,, *lirata* (Sow.)
Strophomena antiquata (Sow.)
,, *corrugatella* (Dav.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)

Mrs. Gray has obtained the following additional species from the same strata at Woodland Point:

Ischadites antiquus (Salt.)
Monograptus gregarius (Lapw.)
,, *leptotheca* (Lapw.)
,, *tenuis* (Portl.)
Diplograptus confertus (*modestus*) (Nich.)
Clathrodictyon vesiculosum (N. and Murie.)
Halysites catenularia (Linn.)
,, sp.
Heliolites foliaceus (Nich. & Eth.)
,, *interstinctus* (Linn.)
Plasmapora girvanensis (Nich. & Eth.)
Glyptocrinus sp.
Fenestella assimilis (Lonsd.)
,, *Milleri* (Lonsd.)
,, *patula* (M'Coy.)
,, *subantiqua* (D'Orb.)
Glauconome disticha (Goldf.)
Gorgonia regularis (Portl.)
Hippothoa inflata (Nich.)
Ptilodictya dichotoma (Portl.)
,, *lanceolata* (Goldf.)
Rhinopora verrucosa (Hall.)
Acidaspis Brighti (Murch.)
Calymene Blumenbachi (Brong.)
Encrinurus punctatus var. *arenaceus* (Salt.)
,, ,, var. *calcareus* (Salt.)
Illœnus (*Bumastus*) *barriensis* (Murch.)
,, (*Dysplanus*) *Thomsoni* (Salt.)
Lichas sp.
Dinobolus Davidsoni (Salt.)
Leptæna scissa.
Orthis pentlandica (Dav.)
,, *sowerbyana* (Dav.)
Strophomena æmula (Salt.)
,, (*Rafinesquina*) *deltoidea* (Conr.)
Triplesia monilifera (M'Coy.)
Ambonychia amygdalina (Hall.)
,, *orbicularis* (Conr.)
Avicula elliptica (Hall.)
Cardiola sp.
Goniophora cymbæformis (Sow.)
Mytilus mytilimeris (Conr.)
Bellerophon dilatatus (Sow.)
,, *expansus* (Lindst.)
,, *sphæra* (Lindst.)
,, sp.
Ecculiomphalus sp.
Fusispira elongata (Hall.)
,, sp.
Holopella sp.
Murchisonia sp.
Oriostoma discors (Sow.)
Pleurotomaria alata (Wahl.)
,, *scutulata* (Lindst.)
Conularia aspera (Lindst.)
,, *subtilis* (Salt.)
Cyrtoceras arcuatum (Hall.)
Gomphoceras crater (Blake.)
Oncoceras sp.
Orthoceras angulatum (Wahl.)
,, *distans* (Sow.)
,, *imbricatum* (Wahl.)
,, *mocktreense* (Sow.)
,, *tracheale* (Sow.)
Phragmoceras sp.
Trochoceras aspersum (Barr.)

A comparison of the sections at Woodland Point and Shalloch seems to favour the view suggested by Professor Lapworth (1) that the Scart Grits at Woodland Point and in Woodland Bay are the equivalents of the conglomeratic sandstones and quartz-conglomerate of Shalloch; (2) that the Scart Grits, which seem to overlie the *Diplograptus confertus* (*modestus*) shales are the counterpart of the Saugh Hill Grits: (3) that the *Pentamerus* limestone at Woodland Point corresponds to the coralline band at Shalloch. These conclusions regarding the order of succession of the Llandovery Rocks on the shore south of Girvan may be tabulated as follows, in descending order:

Saugh Hill Sandstones.	2. Scart grits and conglomeratic sandstones. 1. Quartz-conglomerate.
Woodland Beds.	3. Green and black graptolitic shales and mudstones, *Diplograptus confertus* (*modestus*) shales. 2. *Pentamerus* limestone and shales (Woodland). 1. Craigskelly conglomerate (Horse Rock).

In the foregoing paragraphs relating to the Llandovery Rocks at Woodland Point reference has been made to the fact that some of the zones are only accessible at low tide, and that even under these conditions the section is partly obscured by the sandy beach. For this reason their relation to the underlying Barren Flagstones of the Ardmillan series is not quite clear, but it is probable that they are brought into conjunction with that series by a strike fault which runs more or less parallel to the shore.

Tarannon (*part of Dailly Series*, Lapworth.)

The series of strata within the Girvan area which may be regarded as the equivalent of the Tarannon Rocks of Wales extends as a narrow belt along the northern margin of the Silurian plateau from Penkill near Penwhapple Glen to the northern slope of Hadyard Hill, where it is abruptly truncated by the fault which brings it in contact with the Old Red Sandstone and Carboniferous rocks on the south side of the Girvan valley. But even beyond these limits, the irregular strip of Upper Silurian strata which stretches along the northern flank of the uplands from the northern slope of Hadyard Hill by Blair to Straiton, includes a group, named the Drumyork Flagstones, which, on account of their unfossiliferous character and their resemblance to the "Hawick Rocks" of the Southern Uplands, we are inclined to regard as belonging to this division of the Silurian system. This correlation is strengthened by the fact that the Drumyork Flagstones, like the "Hawick Rocks," seem to pass upwards into beds at Blair and Knockgardner which yield a facies of fossils akin to that of Wenlock age. In the case of the beds near Penkill and Bargany they yield an assemblage of fossils sufficiently conclusive for the purpose of correlation. The various sub-divisions of the Tarannon Rocks, which, according to the classification here adopted, include the zones of the Penkill and Bargany groups, established by Professor Lapworth, together with the Drumyork Flagstones, may thus be tabulated in descending order:

Tarannon Series.	*c.* Drumyork Group.	Green flags and shales, unfossiliferous.
	b. Bargany Group.	2. Yellow, blue, and grey flagstones with zones of shales (Blackwood beds). 1. Pale blue thick-bedded flagstones and shales (Glenfoot beds).
	a. Penkill Group.	4. *Cyrtograptus Grayi* mudstones and shales. 3. *Protovirgularia* grits. 2. Penkill flags and shales. 1. Purple shales and mudstones with *Crossopodia*, *Nemertites*, &c.

a. *Penkill Group.*

Penwhapple Glen Section.—The lower portion of this stream, between the outcrop of the Camregan beds and the great fault that brings the Old Red Sandstone into conjunction with the Silurian rocks, affords an excellent section of the various sub-divisions of the Penkill group, ranging from the *Crossopodia* shales to the *Cyrtograptus Grayi* mudstones.

(1) *Crossopodia Shales.*—Immediately to the north of the Camregan beds, above described (p. 535), a great development of finely laminated shale appears, usually of a purple colour, but with occasional green or grey seams, and are either vertical or inclined at high angles to the south-east. Some of the bands are covered with those peculiar markings resembling the tracks of annelids which are so characteristic of the red and purple shales of Tarannon age in the Central Belt of the Southern Uplands. Indeed, lithologically and palæontologically they resemble the purple slates of Thornylee, in the valley of the Tweed. The various forms of markings obtained from these beds are:

Crossopodia scotica (M'Coy.)	*Nereites Sedgwicki* (M'Coy.)
Nemertites tenuis (M'Coy.)	,, *cambrensis* (M'Coy.)

The palæontological evidence is strengthened by the occurrence of graptolites in some thin carbonaceous seams interleaved in the purple and green shales, which present a well-marked Tarannon facies. The following species have been collected by Professor Lapworth from these layers:

Monograptus exiguus (Nich.)	*Rastrites distans* (Lapw.)
,, *Becki* (Barr.)	*Diplograptus sp.*
,, *galaensis* (Lapw.)	*Retiolites obesus* (Lapw.)

(2 and 3) *Flagstones and Grits with Protovirgularia.*—In the Penwhapple section a gradual passage may be traced from the purple mudstones with *Crossopodia* into an alternating series of flaggy bands with green and purple shales, which are succeeded in turn by greywackes and grits, well seen near the foot of Penkill Burn. Northwards from that locality flaggy greywackes supervene and continue as far as the *Cyrtograptus Grayi* beds. This zone of grits and flaggy greywackes, which cannot exceed a few hundred feet in thickness, is believed to be the attenuated representative of the coarse sediments that are so prominently developed in the Llandovery area of the Central Belt. Although fossils are scarce, some of the species of graptolites characteristic of the underlying *Crossopodia* shales have been collected from these beds.

(4) *Cyrtograptus-Grayi Mudstones.*—The grits and flaggy greywackes are followed by finer sediments of considerable interest, from the abundance and excellent preservation of their organic remains. These strata consist of green and purple mudstones,

which contain seams of graptolite shale, resembling lithologically the Wenlock graptolite shales of Riccarton and Kirkcudbright, but the palæontological evidence leaves no room for doubt that they are still a sub-division of the Tarannon series. They are well seen at a prominent bend of the Penwhapple Glen, about 300 yards north of the foot of Penkill Burn, where, on the bank of the stream, they are readily accessible. From this horizon Mrs. Gray has collected the following fossils:

Cyrtograptus Grayi (Lapw.)
Monograptus colonus (Barr.)
,, *concinnus* (Lapw.)
,, *exiguus* (Nich.)
,, *galaensis* (Lapw.)
,, *Hisingeri* (Carr.)
,, *priodon* (Bron.)
,, *Sedgwicki* (M'Coy.)
Rastrites distans (Lapw.)
Retiolites geinitzianus (Barr.)
Cheirurus bimucronatus (Murch.)
Atrypa reticularis (Linn.)
Discina crassa (Hall.)
Orthis calligramma (Dalm.)
,, *reversa* (Salt.)
,, *rustica* (Sow.)
,, ,, var. *rigida* (Dav.)
,, *turgida* (M'Coy.)
Pentamerus rotundus (Sow.)
Strophomena (*Leptæna*) *rhomboidalis* (Wilck.)
Cardiola fibrosa (Sow.)
Lunulicardium elegans (Salt.)
Orthoceras annulatum (Sow.)
,, *Bacchus* (Barr.)
,, *fusiforme* (Hall.)
,, *Grinrodi* (Blake.)

The strata which follow the *Cyrtograptus Grayi* mudstones in the Penwhapple Glen, northwards to the fault, consist of grey flagstones and shales with hard greywacke bands, which are unfossiliferous, and in general are either vertical or inclined at a high angle to the south-east.

b. *Bargany Group.*

The members of this division appear in the streams to the south of Bargany in the Girvan valley, and still further east on the northern slope of Hadyard Hill. Of these sections, perhaps the most interesting is that laid open in Bargany Burn. In its higher portion, thick-bedded grey and green flagstones and shales are met with (Glenfoot beds)resembling those in Penwhapple Glen to the north of the *Cyrtograptus* mudstones. From the point where the stream enters the plantation at Blackwood Head northwards to the fault that bounds the Silurian plateau, a fine exposure of grey, finely laminated flaggy shales may be seen with occasional harder ribs, which, near the waterfall, show excellent examples of overfolding. A few thin seams of carbonaceous matter associated with these strata have yielded specimens of *Monograptus acus* and *Monograptus priodon*. At the eastern limit of the Blackwood Head plantation, where several small burns drain the north-west slope of Hadyard Hill, an interesting fossiliferous horizon appears among the beds of this group. At the foot of one of these rivulets, and about 100 yards south of the fault that brings the Carboniferous rocks in contact with the Silurian strata, blue, grey, and green fissile shales with limestone ribs crop out and are well seen on a cliff beside the

waterfall, where the following fossils have been collected from them by the Geological Survey:

Land plants.
Heliolites interstinctus (Linn.)
Palæocyclus sp.
Discinocaris gigas (Woodw.)
Encrinurus sp.
Orthis calligramma (Dalm.)
,, *polygramma* (Sow.)
Pentamerus oblongus (Sow.)
,, sp.
Oriostoma (*Euomphalus*) *discors* (Sow.)

c. *Drumyork Flagstones.*

The final sub-division of the Tarannon series appears along the southern margin of the narrow belt of Upper Silurian strata which, between Blair and Straiton, on the south side of the Girvan valley (Sheet 14), are faulted against the Lower Old Red Sandstone and associated igneous rocks. Perhaps among the best exposures are those visible in the Lady Burn near the fault to the south of Drumyork Farmhouse, and near the head of Glenmartin Burn to the south and south-east of Blair. The strata consist of green and grey shales, occasionally weathering brown, with flagstones and greywacke bands, which are destitute of fossils. Their prevalent dip is to the south-east at high angles, so that merely from superposition they might be inferred to be stratigraphically the highest members of the Blair and Straiton (Wenlock) series, but in reality they appear to be inverted like the strata along the northern margin of the table-land of Penwhapple Glen, and they are followed towards the north by beds yielding fossils of Wenlock age.

In illustration of the general structure of the ground in which the Caradoc and Llandovery formations, described in the preceding pages, are developed, a section is here given (Fig. 116) drawn from the Old Red Sandstone district southwards by Drummuck across the Craighead inlier, the valley of the Girvan, and Saugh Hill, to the valley of the Stinchar near the railway-station of Pinwherry.

Wenlock (*Blair, Knockgardner, and Straiton Beds*).

The representatives of this division of the Upper Silurian rocks are traceable for a distance of four miles from the neighbourhood of the farm of Blair to the village of Straiton—a tract which is much covered with superficial deposits, but is traversed by several small streams that expose the strata.

The beds which, in the neighbourhood of Blair, immediately succeed the Drumyork Flagstones consist of greenish shales which weather occasionally with a yellowish tint, are associated with bands of greenish greywacke and contain thin seams of carbonaceous shale charged with graptolites. Some good exposures are met with in the Glenmartin Burn—a tributary of the Shiel Burn—about 500 yards east of Blair Farmhouse, where, on the banks of the stream not far to the south of

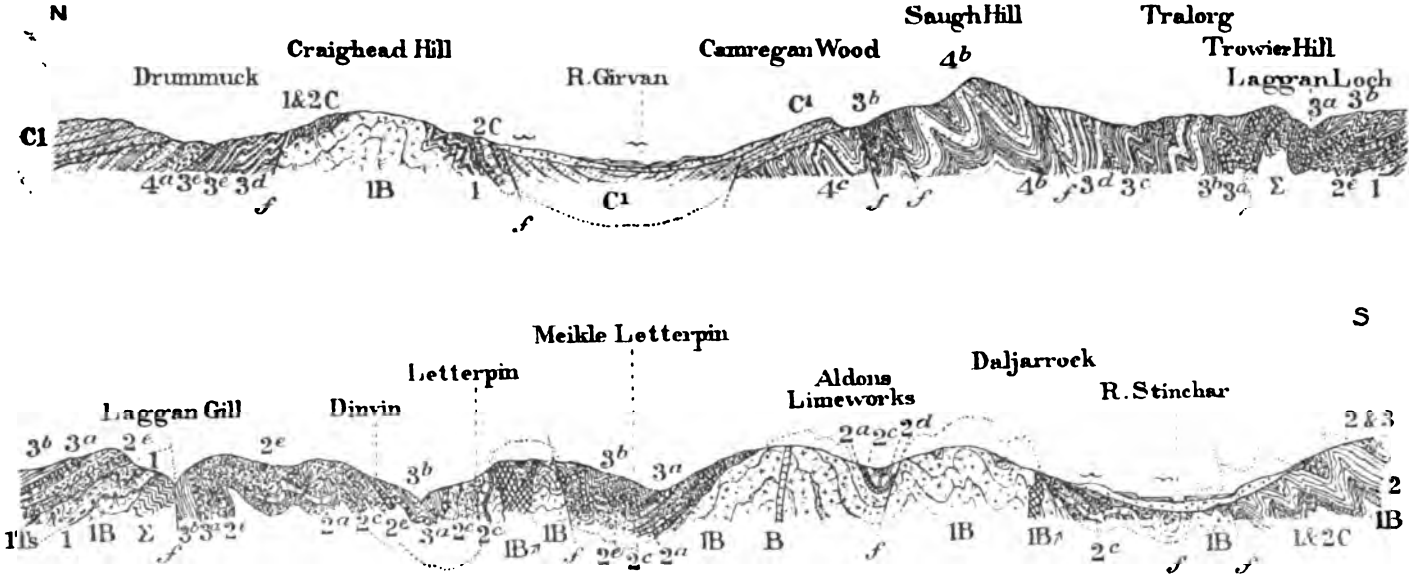


FIG. 116.—Generalised Section across the Girvan Area from Drummuck to River Stinchar, near Daljarrock. (Length, 11 miles,)

1B. Arenig lava. 1Ts. Arenig agglomerate. 1. Arenig black shales. 2. Serpentine. 1BT. Intrusive basic rocks. 2&3C. Radiolarian chert. 2. "Tappins beds." 2&3. Llandeilo-Caradoc. 2a. Kirkland conglomerate. 2c. Stinchar limestone. 2e. Benan conglomerate. 3a. Balclatchie group. 3b. Ardwell group. 3c. Whitehouse group. 3d. Barren flagstone group. 3e. Drummuck group. 4. Upper Silurian (Llandovery Rocks). 4a. Mulloch Hill group. 4b. Saugh Hill group. 4c. Camregan group. C l. Lower Old Red Sandstone. B. Dolerite dyke. f. Faults. ⁓ Boulder clay. ~ Alluvium.

Glenmartin Cottage, green and carbonaceous shales with flagstones from two to three inches thick, yield graptolites and orthoceratites. Still further west, a quarry on the south side of the road, about 150 yards east of Blair Farmhouse, is the best locality for graptolites in the Blair and Straiton region. Here the beds dip to the S.S.E. at 60°, and consist of alternations of green and grey shales, flagstones, and greywacke bands. The shales are variable, some being fissile, others carbonaceous and decomposing with a yellowish tint, while some are calcareous and have a rough irregular fracture. One highly fossiliferous seam, about eight inches thick, yields specimens of *Monograptus vomerinus* in abundance, together with forms many of which occur in the Wenlock rocks of Riccarton and Kirkcudbright. The fossils given in the annexed list have been collected from this quarry by the Geological Survey:

Monograptus galaensis (Lapw.)
" *priodon* (Bronn.)
" *riccartonensis* (Lapw.)
" *vomerinus* (Nich.)
" sp.
Retiolites geinitzianus (Barr.)
Favosites sp.
Beyrichia Klædeni (M'Coy.)
" *impendens* (Jones.)
Entomis globulosa (Jones.)
Eurypterus sp.
Lingula Symondsi (Salt.)
" sp.
Orthis sp.
Siphonotreta anglica (Morris.)
Cardiola fibrosa (Sow.)
Bellerophon sp.
Orthoceras subundulatum (Portl.)

Professor Lapworth has also recorded *Cyrtograptus* sp. and *Bellerophon wenlockensis* from the same band.

Again, in the Lady Burn, between Brownford Bridge and the southern margin of the unconformable Upper Old Red Sandstone, several outcrops of strata belonging to this horizon, consist of flagstones, blue and grey shales, and occasional greywackes. From these beds Professor Lapworth obtained *Monograptus Flemingi*, *M. vomerinus*, *Cyrtograptus* sp., and *Orthoceras subundulatum*.

To the north-east, in the neighbourhood of Knockgardner, the prolongations of these strata are met with in certain artificial exposures, where they yield organic remains. For instance, in a quarry about half a mile west of Knockgardner Farmhouse, and a few yards north of the road, green shales, flagstones, and grit bands, dipping S.S.E. at 83°, furnish specimens of

Beyrichia Klædeni (M'Coy.)
Primitia sp.
Ctenodonta sp.
Grammysia sp.
Modiolopsis sp.
Orthonota truncata (M'Coy.)
" sp.
Pterinea pleuroptera (Conr.)

Again, in another opening in a field about a quarter of a mile east of Knockgardner, and to the south of the road, fossils occur in great abundance in some of the grit bands. Here the strata consist of yellow-weathering shales, with sandy and gritty flagstones from two to nine inches thick, and dip E.S.E. at high angles; the gritty flagstones, where not decomposed, have a grey

or cream colour, but, when exposed to the action of the weather, have a brown tint. Among the weathered debris of these gritty flagstones at the base of the cliff, casts of fossils may be readily obtained. The following species have been here collected by the Geological Survey:

Favosites sp.
Ptilodictya lanceolata (Goldf.)
Cornulites sp.
Beyrichia Klœdeni (M'Coy.)
Acidaspis sp.
Calymene Blumenbachi (Brong.)
Encrinurus punctatus (Brün.)
„ „ var. *arenaceus* (Salt.)
Phacops (*Acaste*) *Downingœ* (Murch.)
„ *Stokesi* (M. Edw.)
Proetus Stokesi (Murch.)
Atrypa reticularis (Linn.)
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
Orthis (*Platystrophia*) *biforata* (Schl.)
„ *Bouchardi* (Dav.)
„ (*Dalmanella*) *elegantula* (Dalm.)
„ (*Dinorthis*) *flabellulum* (Sow.)
„ *rustica* (Sow.)
Retzia Barrandei (Dav.)
Spirifera sulcata (His.)
Orthoceras sp.

About half a mile still further east, green shales and thin gritty flags, visible in a streamlet running south from Dyke Farmhouse to the Cawin Burn, have yielded specimens of *Ptilodictya*, *Orthoceras MacLareni*, *O. angulatum*, and encrinite stems. Similar strata are observable in the Cawin Burn, which flows eastwards from the Green Hill of Knockgardner to the Girvan Water at Straiton, but no fossils have been recorded from these exposures.

The remaining sub-division of the Wenlock rocks of the Blair and Straiton area differs to some extent in lithological character from the strata just described, inasmuch as it contains prominent bands of conglomerate or conglomeratic sandstone. Owing to the sinuous nature of the boundary-line of the unconformable Upper Old Red Sandstone as it passes transgressively across successive zones of the Upper Silurian Rocks, it is not possible to trace continuously the conglomeratic series. But the beds are visible in a wood and in a streamlet north of Cawin Burn, north of the road leading to Knockgardner, and about three-quarters of a mile west of the village of Straiton, where they consist of purple and grey conglomerates and flags, associated with green shales and mudstones. They are either vertical or highly inclined to the south-east, thus presenting an inverted dip in common with the Upper Silurian rocks of the rest of the surrounding district. About two miles further to the south-west, midway between Knockgardner and Kirkbride, the prolongations of this sub-zone reappear at the margin of the Upper Old Red Sandstone, as massive conglomerate and grit in a quarry now abandoned.

CHAPTER XXIII.

IV. THE SOUTHERN BELT.

WENLOCK AND LUDLOW.

ALONG the southern margin of the Silurian Tableland a narrow belt of territory is occupied by rocks of Wenlock and Ludlow age, which rest conformably on the underlying Tarannon sediments to the north, and pass underneath the Upper Old Red Sandstone and Carboniferous strata to the south. A small development of these rocks is to be found on the promontory of Burrow Head, west of Wigtown Bay, their extreme south-westerly limit. From where they reappear on the shores of Kirkcudbright Bay, eastwards to the granite mass of Bengairn, they occupy a strip of ground about two miles and a half broad. From the margin of the Red Sandstone basin at Dumfries, they can be traced as an irregular belt, about five miles wide, north-eastwards by Lockerbie to Mosspaul, and thence to the Slitrig Water, which joins the Teviot at Hawick. Beyond these limits they appear on the northern slopes, and even on the crest of the Cheviots as inliers among younger Palæozoic rocks, ranging from the Lower Old Red Sandstone to the Carboniferous systems.

Burrow Head, Wigtownshire.—The exposures on this rocky headland, though difficult of access, are of considerable interest, because at one or two localities the finest specimens of *Cyrtograptus Murchisoni*, the zonal graptolite of the Lower Wenlock beds, have been collected by the Geological Survey from this horizon. A further attractive feature of this coast is the evidence supplied by the range of sea-cliffs of the perfect passage from the underlying Tarannon rocks to the base of the Wenlock formation.

The shore section from the Isle of Whithorn southwards, affords a typical development of the Hawick Rocks, which there consist of alternations of greenish greywackes, mudstones, and green and grey shales, with zones of purple shales. The greywackes become more massive, till near Morrach Farmhouse flaggy greywackes alternate with zones of mudstones and shales, the whole series being repeated by normal and isoclinal folds. The general dip of the strata and of the axial planes of the flexures is towards the south-east.

Immediately to the south of Morrach Farmhouse this series is succeeded by green and grey greywackes and shales with bands of dark graptolite shales, similar to those which are

so well developed on the shores of Kirkcudbright Bay, to be referred to presently. At a point on the coast, named "The Thieves' Hole" on the six-inch map, half a mile north-east of Burrow Head, the graptolite shales appear at the base of the cliff, interbedded with grey shales and greywackes, and dipping towards the south-east at an angle of about 70°. Traced along the strike towards Burrow Head, these shales are seen at the "Devil's Bridge" and one or two other accessible points, where they yield a similar assemblage of graptolites.

The best place for collecting graptolites will be found on the shore about 400 yards west from Burrow Head, and about 100 yards west from an old fort, now in ruins, where the fossiliferous band dips towards the south-east at high angles, and is associated with greywackes and grey argillaceous shales. Here fine specimens of *Cyrtograptus Murchisoni* can be obtained. The fossils given in the annexed list have been collected from this exposure by the Geological Survey:

Cyrtograptus Murchisoni (Carr.)
„ *Carruthersi* (Lapw.)
Monograptus Flemingi (Salter.)
„ *priodon* (Bronn.)
„ *vomerinus* (Nich.)
„ sp.
Retiolites geinitzianus (Barr.)
Heliolites (?)
Crinoid stems.
Aptychopsis elongata (Jones.)
Ceratiocaris sp.
Orthoceras sp.

District between the Dee and the Nith.—From the Geological Map of the Silurian Tableland, which accompanies this volume, it will be seen that the representatives of the Wenlock and Ludlow rocks of the Silurian system occur on both sides of Kirkcudbright Bay, whence they stretch eastwards by Dundrennan to the granite of Bengairn. A strip of altered strata belonging to the same series is traceable along the shores of the Solway Firth to the hill slopes south-east of Criffel. The character of the rocks is admirably seen on the coast sections, specially on the east side of Kirkcudbright Bay, and onwards to White Port, where they are unconformably overlain by the basement breccias of the Lower Carboniferous series.

The strata may be grouped in two sub-divisions, given here in descending order:

(*b*) Green and olive shales with limestone nodules, grey sandy flags, and thin-bedded greywackes, with occasional bands of fossiliferous grit and conglomerate.

(*a*) Yellow and brown-crusted greywackes and grits, with flags and shales. The chief characteristic of this group is the constant occurrence in it of dark shales charged with graptolites.

The members of the lower group (*a*) occur on both sides of Kirkcudbright Bay. On the eastern shore they extend from the base-line at Long Robin to near the mouth of Balmae Burn, presenting a constant repetition of well-bedded greywackes, grits, and flags with pale and dark coloured shales. On weathered surfaces, the greywackes have a brown tint; in fresh fracture they are grey and blue. The average thickness of each bed

varies from one to two and sometimes to three feet. The pale-coloured shales are argillaceous, and are frequently cleaved, the cleavage-planes trending in the same general direction as those of the Hawick type of the Llandovery group already described. The graptolite bands differ lithologically from the black shales of the Moffat series. Weathering with a dark brown crust, they have a dark colour on fresh fracture, and also a fibrous texture. They sometimes occur in zones from ten to twelve feet in breadth; and, on the other hand, it occasionally happens that thin leaf-like seams, charged with graptolites, alternate with the barren pale-coloured shales and flags of the group. At one locality, on the shore near Witchwife's Haven, about half a mile south of Long Robin, limestone nodules occur in one of these graptolite bands.

This lower sub-division of the Wenlock beds is repeated by rapid folds, as was long ago pointed out by Professor Harkness.* The plications are so numerous that no well-marked axis can be traced inland from the shore. Indeed, from the frequent changes of dip, it is evident that the various outcrops of graptolite-shale are merely repetitions of a few bands. Towards the south, in the broader synclinal folds, the members of the overlying sub-division are to be found. The exposures of the graptolite-shale group on the cliff at Clinking Cove, west of Raeberry Castle, and again, still further to the south-east, in Mulloch Bay, are evidently due to anticlinal folds, the intervening areas being occupied by younger strata.

Few species of graptolites occur in the graptolitic bands. They include *Monograptus vomerinus*, *M. priodon*, *M. riccartonensis*, *M. colonus* (?), *M. Flemingi*, *Cyrtograptus Murchisoni*, and *Retiolites geinitzianus*. Fragments of crustaceans and orthoceratites are associated with the graptolites. The carapace of a crustacean—*Aptychopsis oblata* (Jones)—was found in one of the graptolite-bands immediately to the south of Torr's Cove Bay. Many of the orthoceratite remains are so fragmentary that the species are hardly determinable. The best specimens have been obtained near the Witchwife's Haven, Torr's Point, and Balmae Haven. The strata associated with the graptolite-bands have hitherto yielded no organic remains.

The members of the lower sub-division also occur on the west side of Kirkcudbright Bay, round the shores of Balmangan and Falbogue Bays, in the peninsular tract of Meikle Ross and in the island of Little Ross. Here, also, they present the same features as those already indicated, and they have yielded similar organic remains. Near the base, on the shore, one-third of a mile north of Balmangan Bay, *Cyrtograptus Murchisoni* is one of the characteristic forms.

The graptolite-bearing group has been traced from the east shore of Kirkcudbright Bay to the contact zone round the granite of Bengairn. At various places throughout this belt of ground,

* Quart. Jour. Geol. Soc., vol. ix., p. 183.

graptolites have been obtained from the dark bands. No fossils have been exhumed from the strip of altered Upper Silurian strata along the Colvend shore; but graptolites and orthoceratites have been found in the Wenlock beds in the Kirkbean Burn to the south-east of Criffel.

The members of the higher group (*b*) are admirably seen on the shore between the mouth of Balmae Burn and Howell Bay, along the Raeberry cliffs, and between Mulloch Bay and White Port. The most prominent among them are green and olive shales, with fossiliferous limestone-nodules and ripple-marked sandy flags. These are occasionally associated with sandstones, grits, and bands of fossiliferous conglomerate. They seem to have been deposited in shallow water on a shelving platform, subject to gentle earth-movements. The fossiliferous brecciated conglomerates, intercalated with the olive shales, are evidently old beach-deposits. The gradual thinning out of the sandstones and grits, and the overlapping of the flags and shales, point to repeated changes in the distribution of the materials by currents along the shore.

From the small trough north of Gipsy Point, the following is the arrangement of the strata, between the Balmae Burn and the reappearance of the graptolite-bearing bands in Howell Bay. Immediately to the north of the mouth of Balmae Burn, a fault occurs with a down-throw to the west. On the east side of this fault, the strata consist of brown-crusted greywackes, shales, flags, and graptolite-bands, dipping to the south-east at 70°. These are succeeded by green fissile shales, with bands of flaggy shale from two to three inches thick. For a short distance the beds are inclined to the north at high angles, being here inverted, but they soon dip to the south-east at an angle of 80° till at the mouth of Balmae Burn they pass underneath a lenticular band of fine conglomerate, which may be the attenuated representative of the fossiliferous conglomerate at Gipsy Point, on the south side of the trough.

Southwards, this conglomerate is overlain by olive shales and flags, intersected with veins of calcite, which, within a short distance, have a return dip to the north-west at high angles. Here a zone of finely laminated olive shales, with limestone-nodules, is exposed on the shore, succeeded by ripple-marked greywackes, flags, and shales, graduating into the coarse grits and conglomerates at Gipsy Point. At this locality some excellent examples of the gradual thinning out of bands of grit are visible on the beach and on the cliff. Two outcrops of conglomerate at this headland lie about 70 yards distant from each other. The matrix of the rock is a grey grit, in which are embedded pebbles of greywacke and grit, with angular pieces of shale and rounded grains of quartz. The north band of conglomerate has yielded casts of *Pterinea* and *Petraia;* and the south band *Petraia elongata*, *Favosites*, casts of *Heliolites*, *Spirifera*, *Ptilodictya*, *Cornulites*, and a fragment of a trilobite.

Between these outcrops of fossiliferous conglomerate lies a

zone of gnarled green shales containing lenticular patches of coarse grit and numerous nodules of limestone, which measure from a few inches to a foot across, and have yielded some of the best-preserved fossils. Similar shales reappear on the south side of the southern outcrop of conglomerate at Gipsy Head, veined abundantly with carbonate of lime. They dip to the north-west at angles of from 83° to 88°, and can be traced along the shore to the centre of Howell Bay. Among the fossils obtained from the limestone-nodules may be mentioned *Orthonota*, *Murchisonia obscura*, *Ctenodonta*, *Cucullella*, and *Bellerophon trilobatus*.

In the centre of Howell Bay this group of olive shales, with limestone-nodules and fossiliferous conglomerates, is brought into conjunction with the underlying graptolite-bearing group by means of a fault with a down-throw to the west. Here the strata are traversed by several small faults which have interfered with the natural stratigraphical sequence. On the cliff on the east side of the bay, the graptolite-bearing beds are inclined to the north-west; while east of the headland, towards Clinking Cove, the prevalent dip is to the south-east. These beds are apparently brought to the surface along an anticlinal fold traceable eastwards to the centre of the bay west of Raeberry Castle. The strata consist of brown-crusted greywackes with shaly partings, and the characteristic graptolite-shales. The latter are best seen at Brandy Craig on the east side of Howell Bay, where they have yielded specimens of *Monograptus vomerinus* and *Dictyocaris*. The occurrence of *Monograptus vomerinus* close to the olive mudstones and shales with limestone nodules is worthy of note, as it is one of the forms that occur in the higher graptolite-bands in the Wenlock group of the South of Scotland.

In the centre of the bay, west of Raeberry, the graptolite-bearing group is much disturbed by faults, and has been thrown into a series of sharp folds. It is traversed by a number of intrusive dykes, of which only a few could be engraved on the one-inch map. On the east side of the bay, the strata have a persistent dip to the south-east, in the direction of Raeberry Point, where they consist of ripple-marked micaceous sandstones, flags, and olive shales. The thinning out of the gritty sandstones is well displayed on the beach at this locality, and occasionally small seams and pockets of sand may be observed in the shales. At Raeberry Point a beautiful specimen of *Orthoceras Etheridgei* (Blake) was found in the flaggy shales with limestone-nodules; indeed, upwards of fourteen examples of this species were here obtained. Professor Harkness also found specimens of *Terebratula lacunosa* and *T. semisulcata*.

From Raeberry Point eastwards to the mouth of Dunrod Burn, the shore affords a continuous section of grey flaggy sandstones, in beds averaging from six to twelve inches in thickness, flaggy shales, and green fissile shales. A zone of olive shales with small limestone nodules occurs immediately to the west of Robb's Craigs, in the centre of which a band of coarse grit forms a prominent feature on the beach. A striking characteristic of

the sandstones and flags on the beach at Raeberry is the prevalence of ripple marks. The cliffs display excellent examples of rapid folds and inversions, and of variations in direction of dip along the same line of strike.

The strata just referred to are not prolonged eastwards into Mulloch Bay, in the centre of which the graptolite-bearing strata appear, forming skerries on the beach. Well preserved graptolites have here been obtained from the dark bands associated with the greywackes. It is evident, therefore, that a fault intervenes with a downthrow to the west, separating the graptolite shales from the Raeberry Castle beds.

The section exposed on the beach from the mouth of the Quartercake Burn on the side of Mulloch Bay, south to Netherlaw Point and onwards to White Port, closely resembles that between the mouth of the Balmae Burn and Howell Bay already described. The beds are inclined to the west of north, and there is a similar descending series from the olive shales with limestone-nodules at the mouth of the Quartercake Burn to the fossiliferous conglomerate and associated shales at Netherlaw Point. At the White Port the green shales have been reddened by the infiltration of iron oxide from the overlying red breccias at the base of the Carboniferous system.

The members of the upper sub-division are also exposed at Abbey Burnfoot, in the lower reaches of the Abbey and Netherlaw Burns, and also in the Dunrod Burn north of Burnside. A band of fine brecciated conglomerate, exposed at the farmhouse of Little Balmae, has yielded the following organic remains:

Petraia elongata (Phill.)
„ *bina* (Lons.)
Favosites sp.
Stenopora (*Favosites*) *fibrosa* (Goldf.)
Syringopora.
Heliolites sp.
Encrinite stems.
Cornulites sp.
Ptilodictya sp.
Phacops caudatus (Brün.)
Spirifera sp.
Leptæna sericea (Sow.)
Orthis calligramma (Dalm.)
„ *Bouchardi* (Dav.)
Pterinea sp.
Murchisonia sp.

In a review of the palæontological evidence obtained from the strata overlying the Tarannon Rocks in Kirkcudbright Bay, it is clear that the graptolites, though numbering few species, are of great service for purposes of correlation. The fossils collected by Mr. Fleming and the Rev. Mr. Underwood, and forwarded to the Geological Society of London by the Earl of Selkirk, led Mr. Salter to the conclusion that the strata are of Wenlock age—a view which was confirmed by the evidence obtained by Professor Harkness. There can be no doubt that the graptolite-bearing group belongs to this division of the Silurian system. As already indicated, the lowest graptolite-band on the west side of Kirkcudbright Bay yields *Cyrtograptus Murchisoni*, and the highest bands in contact with the olive shales with limestone-nodules, *Monograptus vomerinus*. But from some of the fossils obtained from the limestone-nodules, it

is probable that the upper group (*b*), comprising the olive shales, may be of Ludlow age.

District between Dumfries and Langholm.—Throughout the area which stretches from the Red Sandstone basin of Dumfries north-eastwards by Lockerbie to the pastoral district north of Langholm, a zone of massive grits has been traced at the base of the Wenlock formation that indicate a slight change in physical conditions from those which prevailed during the deposition of the Hawick type of rocks. The dominant members of this zone are brown-crusted greywackes, flags, and shales with dark-brown graptolitic shales. Indeed, the presence of these constantly recurring fossiliferous shales is the characteristic feature of the group.

The lowest band of graptolite shale above the base of the formation, about a foot in thickness, has been traced for several miles along the southern slope of the valley of the Stennies Water, which joins the Esk about six miles north-west of Langholm (Sheet 10, of the Survey Map), where it is highly fossiliferous, the characteristic graptolite being *Cyrtograptus Murchisoni*. In a streamlet east of Nether Stennies Water, 6½ miles N.N.W. of Langholm, the following fossils were collected from this band:

Cyrtograptus Murchisoni (Carr.)
Monograptus vomerinus (Nich.)
Aptychopsis Wilsoni (Woodw.)
Orthis reversa (Salter.)
Hyolithes (*Theca*) *reversus*? (Salter.)
Orthoceras Nicholianum (Blake.)
Heliolites interstinctus (Linn.)

Owing to the plication of the strata this fossiliferous band is again brought to the surface upwards of a mile to the south-east of the outcrop just referred to, near the head of Rig Burn, about five miles N.N.W. of Langholm, where it has yielded:

Cyrtograptus Murchisoni (Carr.)
Monograptus vomerinus (Nich.)
,, *priodon* (Bronn.)
,, *Barrandei* (Tullb.)
,, *exiguus* (Nich.)
Retiolites geinitzianus (Barr.)
Aptychopsis ovata (Jones & Woodward.)
Ceratiocaris sp.
Orthis reversa (Salter.)

Again, near the head of Woolfhope Burn, Ewes Water, the following species were obtained from the same band of graptolitic shale:

Cyrtograptus Murchisoni (Carr.)
,, sp.
Monograptus vomerinus (Nich.)
Retiolites geinitzianus (Barr.)
Orthis reversa (Salter.)
Aptychopsis ovata (Jones & Woodward.)
Orthoceras annulatum (Sow.)
,, sp.

Far to the south-west, on the west bank of the Corrie Water, a tributary of the Water of Milk, near South Corrielaw, this band has been detected, as indicated in Sheet 10. It has there yielded *Monograptus vomerinus*, *M. galaensis*, *M. priodon*, *Orthoceras annulatum*, and *Orthoceras* sp.

Higher up in the series, other bands of graptolite-shale occur, which individually sometimes reach a thickness of 50 feet, but they are not so fossiliferous as the band just referred to. From an exposure of one of these higher bands in the course of the Annan, at Linkmill, Dormont House, four miles south of Lockerbie, the fossils given in the annexed list were obtained:

Monograptus priodon (Bronn.)
,, *riccartonensis* (Lapw.)
Ceratiocaris inæqualis ? (Barr.)
Orthis (*Dinorthis*) *flabellulum* (Sow.)
Orthoceras sp.

Yet again, another exposure, in the Gimmenbie Burn, Milk Water, near Gimmenbie Mains, three miles south-east of Lockerbie, furnished:

Cyrtograptus sp.
Monograptus priodon (Bronn.)
,, *riccartonensis* (Lapw.)
Ceratiocaris papilio (Salter.)
Orthoceras with central siphuncle.
,, sp.

Owing to the intense folding of the strata, it has not been possible to fix the exact number of the bands of graptolitic shale in the district now under description. As yet the fine olive shales with limestone nodules overlying this series in the shore section south of Kirkcudbright have not been detected between Dumfries and the valley of the Esk. On the hill slope, however, above Langholm Lodge at Wrae Hill, and also in the Ewes Water, a bed of fossiliferous grit has been found to contain fragments of crinoids, corals, and brachiopods in an imperfect state of preservation, like the band at Gipsy Point, Kirkcudbright. Throughout the region, between Dumfries and Langholm, isoclinal folding prevails, giving rise to constant reduplication of the strata, with a general south-easterly dip. One of the best examples of this phenomenon occurs at Langholm Lodge, in the bend of the Esk opposite the ancestral domain, where the graptolitic shales have been rudely cleaved.

District between Langholm and the River Jed.—The Wenlock and Ludlow Rocks of the Border territory naturally fall into three sub-divisions, which are here given in descending order.

(*c*) Green mudstones and marly beds, with nodular calcareous bands, similar to the Raeberry Castle group on the Kirkcudbright shore.

(*b*) Grey, green, and brown, often purple-stained mudstones and shales, frequently occurring in thick zones, with greywackes and grit bands, some of which are massive and pebbly. The characteristic feature of this sub-division is the occurrence of dark-brown flaggy shales charged with graptolites, orthoceratites, phyllopod crustaceans, and sometimes *Eurypterids*. These brown bands vary in thickness from seams interleaved in grey shales to zones fifty feet in thickness. The pebbly grits usually contain fragments of brachiopods, corals, crinoids, &c.

(*a*) Greenish grey flaggy grits, separated by grey shale bands, some of which are crowded with *Crossopodia, Nemertites,* and other tracks, resembling those found in the Hawick Rocks. The members of this group pass conformably downwards into the Tarannon strata of Hawick.

Beginning with the lowest sub-division (*a*), we find the grits along the northern margin of the Wenlock area, where they form a belt of high ground about a mile broad, rising to a height of upwards of 1950 feet. They probably reappear as inliers on the crests of the anticlines among the members of the overlying sub-division (*b*); as, for instance, along the northern slopes of Cauldcleuch Head, by Langtae Hill, Anton Heights, to Frodaw Height, which is indeed the most prominent mass of elevated ground on the south-west part of Sheet 17, of the Survey Map, and the north-west corner of Sheet 11. At one locality on the Slitrig Water, immediately below Stobs Castle, the shales and the surfaces of the greywackes of this sub-division are crowded with tracks.

With the exception of the tracts just referred to, nearly the whole of the remainder of the Wenlock and Ludlow areas between Langholm and Oxnam is floored by the members of the middle sub-division (*b*). The graptolitic shales constantly reappear throughout this region and yield some, if not all, of the characteristic forms. Though the localities from which the fossils have been obtained are now many miles distant from each other across the strike of the beds, yet it is highly probable that the various outcrops are merely repetitions by folding of two or three bands. There is abundant evidence of isoclinal folding. Along the northern edge of the Wenlock series the members of the lowest sub-division (*a*), together with the underlying Tarannon strata, are isoclinally folded, the dip of the axial planes being towards the south-east at angles varying from 30°-80° South of this belt lies a broad area where the axial planes of the flexures are nearly vertical, while still further south, as, for instance, near Langholm, they have a persistent dip to the south-east.

Of the numerous fossiliferous localities between Langholm and Oxnam, a few may suffice for special reference, in order to show the persistent similarity of the assemblage of organic remains. One of the best is certainly that at Stobs Castle Gate, at the junction of a small tributary with the Slitrig Water, four miles south of Hawick, where the graptolitic shale has yielded the following forms:

Cyrtograptus Murchisoni (Carr.)
„ *Carruthersi* (Lapw.)
Monograptus priodon (Bronn.)
„ *vomerinus* (Nich.)
„ sp.
Retiolites geinitzianus (Barr.)
Aptychopsis ovata (Jones & Woodward.)
Ceratiocaris papilio (Salt.)
Eurypterus sp.

About a mile south of Stobs Castle, the Slitrig Water is joined from the west by the Penchrise Burn, in which the graptolitic shale has furnished the following fossils:

Cyrtograptus Murchisoni (Carr.)	*Aptychopsis ovata* (Jones & Woodw.)
„ *Carruthersi* (Lapw.)	*Orthoceras annulatum* (Sow.)
Monograptus priodon (Bronn.)	„ smooth variety.
„ *riccartonensis* (Lapw.)	„ sp. (1)
„ *vomerinus* (Nich.)	„ sp. (2)

In a streamlet at the head of Skelfhill Burn, a tributary of the Allan Water, about nine miles S.S.W. of Hawick, the graptolitic shale has yielded the following forms:

Plant remains.	*Dictyonema* sp.
Cyrtograptus Murchisoni (Carr.)	*Aptychopsis* sp.
„ *Carruthersi* (Lapw.)	*Ceratiocaris* sp.
Monograptus priodon (Bronn.)	*Discinocaris* sp.
„ *riccartonensis* (Lapw.)	*Orthoceras* sp.
„ *vomerinus* (Nich.)	

Again, from an exposure of graptolitic shale in the Priesthaugh Burn, which joins the Allan Water below Skelfhill, about eight and a half miles S.S.W. of Hawick, the fossils given in the annexed list have been obtained:

Cyrtograptus Murchisoni (Carr.)	*Aptychopsis ovata* (Jones & Woodw.)
„ sp.	Crustacean.
Monograptus priodon (Bronn.)	Linguloid shell.
„ *riccartonensis* (Lapw.)	*Cyrtoceras* sp.
„ sp.	*Orthoceras* sp.

Similar lists might be quoted from many other localities over this belt of country.

Reference has already been made to the occasional presence of fossiliferous grits in this sub-division, of which the band near Langholm Lodge is an example. Another instance occurs at a waterfall at Caulkerton Grain, five miles N.N.W. of Newcastleton, where the following fossils were obtained: *Favosites gothlandicus*, *Glyptocrinus basalis*, *Heliolites*, and a crinoid stem.

Inlier of Riccarton and Wolfelee.—The strata included in this inlier (Sheet 17), form a belt rather more than two miles in width, extending from Doorpool, about a mile and a half east of Hobkirk on the Rule Water to Arnton Fell two miles south-west of Riccarton Junction. In the north, the strata are bounded by the unconformable Upper Old Red Sandstone, with which they form a most irregular junction. Their south-east and north-west boundaries are defined chiefly by two large faults, between which and the Silurian strata patches of Old Red Sandstone rocks make their appearance as overlying masses.* The best exposures occur in Wolfelee Burn and Peden's Cleuch. In the former they consist chiefly of thin bedded blue and grey greywackes and grey shales; in the latter similar beds are laid open, some of the finer-grained shales and greywackes showing obscure cleavage. Some of the greywackes are coarse-grained,

* The Silurian inliers on the slopes of the Cheviots were mainly surveyed by Professor James Geikie, whose descriptive notes are incorporated in the account here given of the strata.

and pass into conglomerates. The coarse grits contain rounded pebbles of white and brown quartz, many of which measure three and six inches across, and they likewise pass into conglomerates with water-worn fragments of quartz, mudstone, shale. Here and there the greywackes are purplish in colour, while the shales are now and again green. The beds are frequently vertical, but have a general inclination to south and south-east.

Various bands of graptolitic shale appear in several burns to the south of Hyndlee, where they yield fossils similar to those in the graptolitic shale to the north. One example may here be quoted, from the Kirn Cleuch, Hyndlee Burn, about four miles south of Hobkirk, where *Cyrtograptus Carruthersi*, *Monograptus riccartonensis*, *Retiolites geinitzianus*, and *Orthoceras subundulatum* were obtained,

In the south-western portion of this inlier near Riccarton Junction, similar evidence is obtained of the intercalation of graptolitic shales with greenish greywacke, grits, and mudstones, which are isoclinally folded, the general inclination of the axial planes being to the south-east. From a band of graptolitic shale in the railway cutting at Riccarton Junction the following forms were collected, viz.: *Cyrtograptus*, *Monograptus vomerinus*, *M. riccartonensis*, *M. priodon*, *Dictyocaris Ramsayi*, and *Orthoceras*. From an exposure in the burn at Riccarton Junction, *Monograptus vomerinus*, *M. Riccartonensis*, *M. priodon*, and *Orthoceras* were gathered, and in the Riccarton Burn, a little below where the railway crosses the stream, *Monograptus riccartonensis*, *M. vomerinus*, and *Orthoceras* were obtained.

Nearly the whole of the Wolfelee and Riccarton inlier is occupied by strata belonging to subdivision (*b*) (p. 558). There is one small patch, however, of the overlying group (*c*). It consists of green mudstones and marly beds with calcareous nodular bands, similar to the beds near Raeberry Castle, on the Kirkcudbright shore. These strata are exposed in the railway cutting about half a mile W.N.W. of Riccarton Station, where they form a strip about 100 yards broad. Their actual thickness probably does not exceed from 30 to 40 feet, for they are repeated by gently undulating folds.

Inliers on the Northern Slopes of the Cheviot Hills.—The Upper Silurian strata included within these limits occur in more or less interrupted patches. One of the largest is that traversed by the Jed Water and the Edgerston Burn. It is everywhere bounded by rocks of Old Red Sandstone age, underneath which the Silurian strata are frequently seen to pass, the boundary lines being, as is usual in such cases, very irregular.

Another large area occurs high up on the slopes of the Cheviots, stretching eastwards to the Hindhope Burn and the river Coquet. The Silurian strata are here again overlain unconformably by rocks of much more recent age. Towards the north they are covered by the Old Red Sandstone volcanic series, their

southern boundary being defined by overlying beds of white sandstone belonging to the Carboniferous series. Insignificant patches of Silurian strata appear here and there beyond the limits of these larger areas, in ravines and stream-cuttings, where the superincumbent strata of Old Red Sandstone have been removed by the denuding action of running water. They may be seen at Willowford Burn and Woodfield Burn, which enter the Jed opposite Mossburnford, and in Richards Cleuch, near Doresford, two miles further up the Jed valley. Two small patches are likewise exposed in the bed of the Jed, a mile or two below Chesters, another is traversed by the Carter Burn at Southdeanrig, and again two similar exposures appear in the headwaters of the Jed near Dun Knowe. Most of these sections present admirable examples of unconformability.

The strata in the various areas now mentioned are evidently prolongations of the beds which occupy the districts already described. They show a pretty constant dip towards the southeast, although now and again the beds roll over and dip in the opposite direction. In many places the strata are on end or nearly so, but more commonly the dip does not exceed 50° or 60°, the inclination being occasionally as low as 15° or 20°. The strata consist generally of thin-bedded blue and grey greywackes and shales, with occasional thicker zones of shale, in which bands and ribs of greywacke are intercalated. The greywackes sometimes become coarse-grained and pebbly, and now and again display ripple-marks on their surfaces. Frequently the greywackes weather with an ochreous crust. Here and there thin seams and zones of graptolite-shale are intercalated in the other sediments, thus linking these strata with the members of subdivision (*b*). Approaching the crest of the Cheviots, the observer finds that the beds continue as usual to show more or less rapid alternations of greywacke and shale; the latter, however, become more common, and the associated greywackes more fine-grained, as the strata are traversed towards the south-east.

In order to show that the graptolitic shale of these inliers yields forms identical with those found in the regions already described, we may quote the following examples. From an exposure on the Jed Water at Doresford, Camptown, five miles S.S.E. of Jedburgh, the following forms were collected:

Monograptus Flemingi (Salt.)	*Monograptus vomerinus* (Nich.)
,, *priodon* (Bronn.)	*Retiolites geinitzianus* (Barr.)
,, *riccartonensis* (Lapw.)	*Ceratiocaris ludensis* (Woodw.)

At the road-side at Camphouse, six miles S.S.E., a band of this material yielded *Monograptus priodon*, *M. vomerinus*, together with fragments of *Monograptidæ*.

Still another instance is to be found about ten miles south of Morebattle, near the crest of the Cheviots, in the Hindhope Burn, which drains the northern slopes at Coquet Head and the sur-

rounding heights, where the graptolitic shale furnished the fossils in the annexed list:

Monograptus priodon (Bronn.)
" *riccartonensis* (Lapw.)
" sp.
Retiolites geinitzianus (Barr.)
Cyrtograptus sp.
Orthoceras sp.
Aptychopsis Wilsoni (Woodw.

CHAPTER XXIV.

V. UPPER SILURIAN ROCKS NORTH OF THE TABLELAND.

Lanarkshire and Ayrshire.

WITHIN the territory occupied by the Old Red Sandstone in the midland valley of Scotland, several inliers of Upper Silurian Rocks make their appearance. They are found in Lanarkshire in the adjoining county of Ayr, and in the counties of Midlothian and Peebles. The Ayrshire and Lanarkshire tract, since the discovery of well-preserved Eurypterids in it by the late Dr. Slimon of Lesmahagow, has become widely known in geological literature. The more important of these inliers are situated several miles to the north of the Silurian Tableland, where they have been brought to the surface by the plication and subsequent denudation of younger Palæozoic rocks.

One of the most interesting features connected with these Upper Silurian areas is the conformable sequence from the Upper Ludlow Rocks, into the Lower Old Red Sandstone. This conformability was clearly recognised by Murchison, Ramsay, A. Geikie, and at a later date by Mr. B. N. Peach when he mapped the region between Lesmahagow and Douglas (see Geol. Survey, one-inch map of Scotland, Sheet 23, published in 1872). In the Explanation descriptive of the geology of the area included in Sheet 23, it is shown that, while the conformable portion of the Lower Old Red Sandstone contains red and yellow sandstones and conglomerates, it likewise includes certain green and red mudstones with bands of grey shale and greywacke, which, in the Lesmahagow district, yielded "*Beyrichia* and some obscure *Pterygotus*-looking crustacean remains."* The occurrence in the passage-beds of certain organisms identical with those in the underlying Ludlow Rocks suggested the recurrence of marine or brackish water conditions during the deposition of the lower portions of the Old Red Sandstone.

In the course of the recent revision of the Upper Silurian inliers in Lanarkshire by the Geological Survey (Sheet 23, of the Map), special attention was paid to the fossiliferous bands in the red passage-beds overlying the Ludlow Rocks. Towards the close of 1896 they yielded to Mr. Macconochie fragments of crustaceans and certain obscure remains resembling ichthyolites. The search was resumed in 1897, and after a prolonged examina-

* Explanation of Sheet 23, page 13.

tion of the various exposures by Messrs. Macconochie and Tait, it resulted in the discovery of a fauna which in some respects is remarkable; for, in addition to representatives of all the genera of *Eurypteridæ* found in the underlying Ludlow Rocks, there is likewise an assemblage of fishes, comprising five genera, four of which and seven species are new. Dr. Traquair, in whose hands the collection of fishes has been placed for determination, has kindly furnished the following notes embodying the results of his researches:—

"The only fishes which have occurred in the 'Ludlow' beds of the Lesmahagow district are *Thelodus scoticus* (Traq.) and *Thelodus planus* (Traq.), besides a fragment of another form, which is too imperfect for description. The list from the 'Passage' or Downtonian beds is larger, and includes the following:—

Thelodus scoticus (Traq.)
Lanarkia horrida (Traq.)
,, *spinosa* (Traq.)
,, *spinulosa* (Traq.)
Ateleaspis tessellata (Traq.)
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)

"All these are new to science.

"The geological interest of this discovery lies in the fact that a new fish-fauna has turned up in the Upper Silurian rocks of Scotland, two genera and several species of which belong to a family, the *Cœlolepidæ* of Pander, which, in strata of approximate age in England and other parts of the world, have hitherto been known only by scattered scales. A few isolated scales of *Thelodus* (*Th. tulensis*, Rohon.) have also occurred in the Upper Devonian of Russia, and the entire fish from the Lower Old Red Sandstone of Forfarshire, named by Powrie *Cephalopterus Pagei*, is now proved to belong to the same genus. Four other genera of striking novelty, *Lanarkia*, *Ateleaspis*, *Birkenia*, and *Lasanius*, also form part of the same fish-fauna, but it is remarkable that as yet no trace has been found in these Lesmahagow rocks of the *Onchus*-spines, of the Pteraspidians, or of the Cephalaspidians which have been long known from the Upper Silurian strata of the west of England and elsewhere.

"Zoologically the interest of these fishes is extreme. The Cœlolepidœ have, from their shagreen-like scales, been considered by many palæontologists to be sharks, and to them have also been referred the undoubted selachian spines known as *Onchus*, and even certain selachian-like teeth such as *Monopleurodus* of Pander. But the recent 'find' of the Geological Survey puts a different face on the matter.

"We have here two genera of Cœlolepidæ—*Thelodus*, whose minute shagreen-scales are of the type seen in the species which occur in the Ludlow Bone-bed and in the Upper Silurian rocks of Oesel, and *Lanarkia*, a new genus in which the dermal covering consists of small, hollow, pointed spines, without a basal plate. In both genera the form of the creature is the same—the head

plus the anterior part of the body being broad and flattened, with right and left posterior angles in the form of fin-like expansions, the contour of which is continuous with that of the head in front but sharply marked off from that of the tail behind, which latter part terminates behind in a deeply cleft heterocercal caudal fin. There is no trace of jaws, of teeth, or of fin spines in any of the numerous specimens which have been collected, nor has the position of the eye been discovered.

"Now, although through their dermal armature the Cœlolepidæ appear related to the sharks, their general form, along with the absence of teeth and the *apparent* absence of jaws, appears rather to claim a place for them in the Ostracodermi and in the order Heterostraci, of which the only family hitherto recognised is that of the Pteraspidæ.

"*Ateleaspis tessellata* is the type of a new family, and presents us with a form in which the body has the same general shape as in the Cœlolepidæ, but the dermal covering consists in front of small minutely tuberculated polygonal plates, while the tail is provided with rhombic scales, ornamented with delicate tubercles and ridges. It reminds us strangely both of *Cephalaspis* and of *Psammosteus*, but more especially of the latter, as the presence of orbits on the upper aspect of the head is doubtful. It is unfortunate that *Ateleaspis* is so exceedingly rare that only one example showing the head and body has as yet been found, nevertheless what we do see of its structure leads us to the conclusion that the Psammosteidæ of the Devonian epoch are, as Reis has already indicated, also Heterostraci, and allied to the Pteraspidæ. And wherever *Psammosteus* goes there also must *Drepanaspis* of the German Lower Devonian find its place. And it may also be said that although the head and body of *Drepanaspis* are covered with plates instead of with minute scales or spines, the general coincidence of the shape of the fish with that of *Thelodus* or *Lanarkia* is exceedingly striking and suggestive.

"The recent 'find' therefore very greatly enlarges our conception of the Heterostraci, and indicates that, though we cannot consider them as actual Selachii, they probably had a common origin with the primitive Elasmobranchs. And it may here be noted that Rohon, though he calls the Cœlolepidæ 'extinct selachians,' and their scales genuine 'placoid-scales,' remarks that, as these scales in many respects show a simple condition of histological structure, they must be regarded as placoid scales in a lower stage of development.

"*Birkenia elegans* is a very peculiar as well as beautiful form, of elegant fusiform shape, with the head and body covered by narrow tuberculated scutes. There is a completely heterocercal bilobate caudal and a rudimentary dorsal fin, but no trace of paired fins, shoulder girdle, cranial bones, jaws, or even of distinct orbits. It is also the type of a new family, but it is doubtful if it can be included in the Heterostraci; more probably it represents a separate division of Ostracodermi.

"*Lasanius problematicus* is the name which I have applied to a fish whose remains show some very remarkable features. Apparently of an elongated form, the only hard parts which it possessed were a median row of small scutes with backwardly directed thorns, and on the opposite side in front a peculiar gridiron-like arrangement of about eight parallel bony rods on each side, whose extremities are, at the margin of the body, bent at an angle inwards to meet their fellows of the opposite side. If the row of scutes is dorsal, then the rods may have had to do with the support of the branchial apparatus. Traces of the body are often seen in the form of a carbonaceous film, and in one or two instances this film seems to terminate behind in an acutely bilobate caudal fin. The affinities of this form are, as the specific name implies, very problematical, though I feel no doubt that it is an Ostracoderm, and almost as little that, in spite of its deficiency in dermal covering, it is allied to *Birkenia*.

"It may, in conclusion, be truly said that this recent discovery of Silurian fishes by the Geological Survey of Scotland has opened out to us a new vista in the field of palæozoic ichthyology."

The interest attaching to this group of rocks in Lanarkshire has been augmented by the recent discovery of ichthyolites in the admittedly Upper Ludlow Rocks of the neighbourhood of Lesmahagow. In 1896 a species of *Thelodus* was collected from one of the upper zones by Mr. James Young, Lesmahagow, and in 1897-8 two new species of the same genus were obtained by Messrs. Macconochie and Tait from the same horizon. It was from this band also, that a fine example of a true scorpion (*Palæophonus*) was collected, which was exhibited to the Geological Society of Edinburgh by Dr. Hunter, Carluke, and described by Mr. B. N. Peach.

The recent palæontological discoveries in these passage-beds of Lesmahagow, prove the presence of so many normal Upper Silurian organisms in shales intercalated in the overlying red and yellow sandstones as to suggest the desirability of grouping these conformable red strata with the Upper Silurian system. Certain data connected with the lithological characters and stratigraphical relations of some of the zones overlying the true Ludlow Rocks seem to favour this view. For example, throughout the Douglas and Lesmahagow districts, two prominent beds of conglomerate have been of great service in working out the geological structure of that region. The lower one, which almost immediately overlies the fish-band above referred to, is composed mainly of pebbles of quartzite derived from the Highlands, while the higher one, which is separated from the lower by red and yellow sandstones and shales, is readily distinguished by the abundance of greywacke pebbles obtained from the Silurian Tableland of the Southern Uplands. Not, indeed, till we reach the horizon of this greywacke-conglomerate do we find

conclusive evidence of the predominance of materials in the passage-beds that have been derived from the Silurian Tableland.

The greywacke-conglomerate preserves its distinctive features, as a well-marked horizon along the northern border of the Silurian Tableland from the Pentland Hills to Ayrshire. It forms the base of the sediments which herald the great volcanic series of the Lower Old Red Sandstone, and is to all appearance intimately associated with the terrestrial movements which preceded or accompanied those manifestations of volcanic activity. For both in the Pentland Hills and in Ayrshire this greywacke-conglomerate denotes a marked unconformability; in the former region, as we shall point out in the sequel, it rests on the upturned edges alike of the Wenlock, Ludlow, and passage-beds, while in the latter area it lies unconformably on Lower Silurian strata. It is remarkable, however, that in Lanarkshire and the adjoining part of the county of Ayr, where this horizon has been traced over many miles of country, no unconformability has been detected between it and the underlying sandstones. Some of the sections seem to indicate a gradual passage from the one series into the other, but even if this feature be deceptive it is at least clear that if a discordance does exist in that part of the country, it must be comparatively gentle.

In view of the palæontological and to some extent also of the physical evidence regarding the passage-beds that overlie the Ludlow Rocks there seems ground for maintaining that they have greater affinities with the Silurian system than with the Old Red Sandstone. They may be looked upon as stratigraphical equivalents of the Tilestones, Downton Sandstones, and Ledbury Shales, which, in Herefordshire, overlie the Upper Ludlow Rocks and have been classified as forming the highest sub-division of the Upper Silurian rocks.* In the following pages a similar grouping has been adopted, and, for the sake of convenience of description, the passage-beds, ranging from the fine local conglomerate underlying the red sandstones to the base of the greywacke-conglomerate, will be referred to as the Downtonian series. This modification in the classification hitherto adopted by the Geological Survey is represented in the annexed table, which gives the various sub-divisions of the Upper Silurian rocks in Lanarkshire in descending order:

Lower Old Red Sandstone.	Volcanic Series.	3. Andesites and tuffs (volcanic zone). 2. Chocolate-coloured sandstones with *Cephalaspis Lyelli*. 1. Conglomerate with greywacke pebbles.

Unconformability in the Pentland Hills and in Ayrshire; apparent conformability in Lanarkshire.

* See for example Sir A. Geikie's "Text-Book of Geology," 3rd ed., 1893, p. 753.

Upper Silurian.	Downtonian.	11. Chocolate-coloured sandstones—1200 feet in Lesmahagow inlier. 10. Conglomerate with large pebbles of quartzite —100 feet in Lesmahagow inlier. 9. Green and red mudstones with bands of grey shale and greywacke, containing a band with fishes and crustaceans—100 feet in Lesmahagow inlier. 8. Red and yellow false-bedded sandstones and red mudstones—1300 feet in Lesmahagow inlier. 7. Conglomerate of local occurrence, with small pebbles of Arenig volcanic rocks, radiolarian chert, quartz, &c., resting conformably on Ludlow shales—88 to 150 feet in the Hagshaw Hills anticline.
	Ludlow.	6. Green flaggy and sandy greywackes, with partings of grey and red mudstone—about 130 feet, 5. Blue, grey, and green shales with sandy mudstones and greywackes, occasionally weathering with a rusty colour—200 feet (*Trochus* beds). 4. Hard blue and grey flaggy shales and mudstones, with occasional bands of calcareous nodules—350 feet (*Pterygotus* beds). 3. Hard grey flagstones and bands of hard greywacke, with bands and zones of dark fissile calcareous flaggy shales, weathering rusty brown—500 feet (*Ceratiocaris* beds and Ludlow fish band). 2. Grey, blue, and olive shales, with occasional greywacke bands—300 feet.
	Wenlock (?)	1. Hard bands of greywacke with shale partings—1300 feet.*

The various areas of Upper Silurian strata in Lanarkshire and the adjacent part of the county of Ayr (Sheets 15 and 23 of the Survey Map) may be grouped as follows according to their size and relative importance:

1. The Lesmahagow inlier.
2. The anticline of the Hagshaw Hills.
3. The Carmichael Burn inlier.
4. The small exposure south of Tinto.

Of the foregoing inliers it is highly probable that the axial fold near Carmichael Manse (No. 3) is merely the north-easterly prolongation of that in the Hagshaw Hills (No. 2) reappearing from underneath the Carboniferous rocks of the basin of the Douglas Water. The most important, however, are the first two of the series, the anticline of the Hagshaw Hills (No. 2) being five miles, and that of the Logan Water (No. 1) from seven to eight miles distant from the northern limit of the

* The thicknesses of the sub-divisions of the Wenlock and Ludlow Rocks given in the above Table apply only to the Lesmahagow inlier.

Silurian Tableland. A careful study of the stratigraphical relations of these two inliers shows that there is a great similarity in the structure of both areas, for in each case the Wenlock and Ludlow Rocks form anticlines, now exposed at the surface by the removal of the Downtonian and Lower Old Red Sandstone strata which covered them to a great depth; each is bounded on the south-east side by a large fault, while along their north-west margins the sequence from the Ludlow to the Downtonian Rocks can be traced. A further interesting feature which illustrates the extreme plication of the Silurian and Lower Old Red Sandstone rocks in pre-Carboniferous time is the prominent inversion of the strata in the case of the Hagshaw anticline. Both limbs of the fold dip towards the north-west. and the south-east limb is truncated by a reversed fault, by means of which older are made to overlie younger rocks. In other words, we have here a repetition of over-folds culminating in reversed faults, which is such a conspicuous feature of the mountain-building of the North-West Highlands. That this plication took place in pre-Carboniferous time is evident from the fact that the Upper Old Red Sandstone and Lower Carboniferous rocks rest unconformably on the folded Downtonian and Lower Old Red Sandstone strata.

i. THE LESMAHAGOW INLIER.

This area lies on the confines of the counties of Lanark and Ayr between Muirkirk and Lesmahagow. The boundary between the two counties forms there a sinuous line running along the watershed that separates the tributaries of the Clyde (Nethan, Kype, and Glengavel Waters) from the Greenock Water and its affluents, which flow into the river Ayr. Though the region lies within the midland valley of Scotland, it nevertheless forms a pastoral district, where some of the hills exceed 1500 feet in height. Excellent sections of the strata are exposed in the various streams, notably in the Logan and Greenock Waters and their tributaries, and as the beds over much of the area dip at gentle angles favourable opportunities are afforded of studying the various palæontological zones (Fig. 117).

Wenlock and Ludlow Series.

The Wenlock and Ludlow Rocks of the Lesmahagow inlier extend in a north-east direction from the Greenock Water by the Priesthill Height (1615 feet) and Nutberry Hill (1712 feet) to the Logan Water, a distance of six miles. In this instance only the northern limb of the anticline has been preserved, as along a portion of the south-east margin the Wenlock and Ludlow Rocks are truncated by a normal fault bringing them in contact with the Downtonian beds. The sequence is still further interrupted by a sheet of intrusive felsite, which runs along the strike of the lowest beds in the core of the fold.

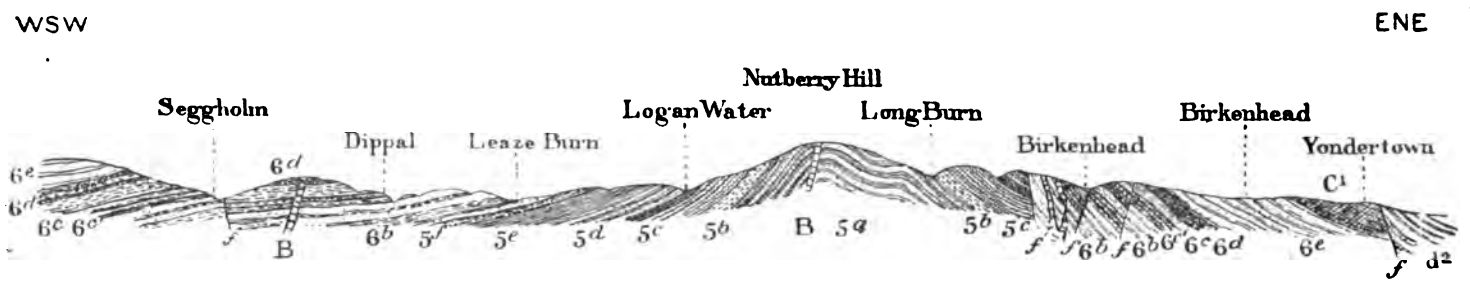


FIG. 117.—Section across the Lesmahagow Upper Silurian Inlier from Seggholm to Yondertown. (Distance, about nine miles.)

d2. Lower Carboniferous formations.

Downtonian.
- 6e. Chocolate-coloured sandstones (No. 11 of Table, p. 569).
- 6d. Quartzite conglomerate (No. 10).
- 6c. Fish-beds (No. 9).
- 6b. Red and yellow sandstones (No. 8). The Glenbuck conglomerate band (6a) is not here present (see Fig. 118).

5a. Wenlock (?).

c1. Lower Old Red Sandstone.

Ludlow.
- 5f. Greywackes and mudstones (No. 6).
- 5e. *Trochus*-beds (No. 5).
- 5d. *Pterygotus*-beds (No. 4).
- 5c. *Ceratiocaris*-beds (No. 3).
- 5b. Shales and greywackes (No. 2).

B. Dolerite dykes (Tertiary). f. Faults.

(1) The lowest beds (No. 1 of the Table given above and 5a of Fig. 117), consist of blue greywackes with partings of shale. They extend along the southern margin of the area, being visible in the head-waters of the river Nethan, in the Ponesk Burn, and in other streams in the direction of Hall on the Greenock Water. Indications of the anticlinal arrangements of these beds are to be found on Nutberry Hill, where, at various points, they dip to the north-west, north-east and south-east. One noteworthy feature connected with this group is the presence of mineral veins (galena and barytes), which have been expressed on the one-inch map, Sheet 23, published in 1872. Few fossils have been obtained from this sub-division; indeed, the only determinable forms, comprising *Orthis* (?) and *Murchisonia*, have been collected from one locality on the north-east slope of Nutberry Hill, where the sandy greywackes and shales dip to the north-west at angles varying from 40°-60°. In the absence of definite palæontological evidence it is impossible to fix with precision the age of the beds forming the lowest group. We are inclined to believe that they may belong in part at least to the Wenlock formation, but this question is one which must be verified by future research.

(2) The members of the next group (Nos. 2 and 5b) consist of grey, blue, and olive shales, with occasional greywacke bands, which form a very narrow strip immediately to the north of the presumably Wenlock strata. They range from the neighbourhood of Hall, in the Greenock Water, to the north-west slope of Nutberry Hill, where, crossing the Long Burn they sweep round the east limit of the anticline towards the river Nethan, west of Eaglinside, their general dip in the latter region being easterly. At one locality, near the head of the Long Burn—a tributary of the Logan Water—at a point about a mile to the south-east of Logan House, the following fossils were collected by the Geological Survey from certain nodular sandy greywackes occurring in this subdivision.

Ceratiocaris papilio (Salt.)
,, *stygius* (Salt.)
Anodontopsis bulla (M'Coy.)
,, *lucina* (Salt.)
Ctenodonta obesa (Salt.)
Mytilus mytilimeris (Conr.)
Orthonota amygdalina (Sow.)
,, var.
,, *bulla* (Salt.)
Orthonota impressa (Sow.)
,, *solenoides* (Sow.)
Pterinea retroflexa (Wahl.)
,, ,, var. *naviformis.* (Conr.)
,, *pleuroptera* (Conr.)
Holopella obsoleta (Sow.)
Murchisonia sp.
Platyschisma helicites (Sow.)

(3) The *Ceratiocaris*-beds (No. 3 and 5c) are of special interest, as they contain the layer which has recently yielded the Ludlow fishes. Lithologically the sediments of this group are coarser than those of the underlying and overlying groups. They consist of hard grey flagstones and bands of hard greywacke, in which occur zones of dark fissile calcareous flaggy shales. The latter contain in remarkable abundance at certain localities

remains of *Ceratiocaris*, which is indeed the distinctive palæontological feature of the sub-division.

The Geological Map (Sheet 23) shows that the members of this group extend along the northern limb of the anticline from Linburn on the Greenock Water north-eastwards to the Logan Water, where the finest exposures of the *Ceratiocaris* beds are to be seen. Thence they curve round the eastern termination of the arch towards the Nethan Water at Eaglinside.

At various points in the Logan Water the fossiliferous bands of this subdivision (No. 3 and 5c) are admirably displayed; indeed, owing to the gentle inclination of the beds, large surfaces of the more important seams are laid bare for investigation. Though fragments of the characteristic crustaceans are found on different horizons throughout the group, one band is of special importance from the abundance of species of *Ceratiocaris* in it, and from the occurrence of Ludlow fishes, and a well-preserved scorpion. The group is exposed in a small gorge in the midst of a plantation about three-quarters of a mile to the north-east of Logan House. Here the stream-course makes a marked loop at a place known locally as Shank's Castle. The hard greywackes and flagstones at the southern curve of the loop dip to the north-west at 15°, being succeeded up-stream by rusty-brown calcareous flaggy shales, from which the following organisms bave been obtained:

Worm tracks.
Ceratiocaris laxa (Woodw. & Jones.)
,, *longa* (Woodw. & Jones.)
,, *papilio* (Salt.)
Ceratiocaris stygius (Salt.)
,, telson, like *Murchisoni* (M'Coy.)
Slimonia acuminata (Salt.)

Above the wood a large alluvial flat extends up stream for half a mile to Logan House, where operations are now in progress for the formation of a large reservoir. Not far to the west of Shank's Castle, where excavations are now being made for an embankment, the fossils given in the annexed list were collected from the debris of this band:

Worm tracks.
Myriapods ? (impressions of).
Ceratiocaris sp.
Dictyocaris Ramsayi (Salt.)
Pterygotus bilobus (Salt.)
Slimonia acuminata (Salt.)
Thelodus scoticus (Traq.)

Though the remains of Eurypterids are numerous, only two fragments of the Ludlow fish, *Thelodus scoticus*, were here obtained, which, however, are sufficiently distinct for determination.

As the Ludlow fish-band is followed westwards its outcrop is affected by two normal faults. The first, trending in a north-west and south-east direction not far to the west of Shank's Castle, shifts the outcrop to the north side of the valley; the second, trending E.N.E. and W.S.W., produces a still further displacement towards the north-west. Near Logan House,

certain members of the *Ceratiocaris*-group—though on a slightly lower horizon than the fish-band—appear at the foot of the Long Burn, a tributary of the Logan Water. Here the blue greywackes and shales dip towards the north-west at angles varying from 20° to 35°, and contain the following forms:

Spirorbis sp.
Beyrichia Klædeni (M'Coy.)
,, ,, var. *torosa* (Jones.)
Ceratiocaris.
Dictyocaris Ramsayi (Salt.)
Pterygotus bilobus (Salt.)
Lingula minima (Sow.)
Modiolopsis Nilssoni (His.)
Orthonota sp.
Platyschisma (*Trochus*) *helicites* (Sow.)

About Logan House the stream has laid open various exposures of greywackes and shales having a similar inclination to the north-west, till at a point about half a mile south of the farmhouse the best development of the Ludlow fish-band in the Lesmahagow inlier is displayed. From this locality, also, the finely-preserved scorpion, *Palæophonus caledonicus*, was obtained. Here the stream for a short distance flows in an E.N.E. direction, and obliquely crosses the strike of the beds, which dip to the W.N.W. at angles varying from 12°–15°. On the left bank the strata form a cliff about thirty feet high, the upper portion of which consists of hard greywacke bands about a foot thick, and the lower of brown flaggy shales which contain the remains of *Ceratiocaris* in abundance, with a few fragments of *Pterygotus*. The fishes are partly embedded in ironstone nodules in the brown flaggy shales. These nodules are sometimes arranged in lines close to each other, and the organic structures are found to be much better preserved in them than in the ordinary flaggy shales. The following fossils have been collected from this outcrop by the Geological Survey:

Archidesmus loganensis (Peach.)
Ceratiocaris longa (Jones & Woodw.)
,, *Murchisoni* ? (M'Coy.)
,, *papilio* (Salt.)
,, *stygius* (Salt.)
Slimonia acuminata (Salt.)
Physocaris sp.
Pterinea retroflexa (Wahl.)
Platyschisma (*Trochus*) *helicites* (*Sow.*)
Thelodus scoticus (Traq.)
,, *planus* (Traq.)
Fish fragment undt.

In the valley of the Greenock Water, another exposure of these beds is to be seen at Linburn, where they yielded specimens of *Ceratiocaris papilio*, *C. robusta*, *C. stygius*, and *Thelodus scoticus*.

(4) The *Pterygotus*-beds, the strata so successfully explored by Dr. Slimon of Lesmahagow, though traceable from end to end of the anticline as a narrow belt lying to the north of group No. 3, are best exposed in the Logan Water and its tributaries. At Dunside, on the south bank of the Water, the strata dip to the W.N.W. at an average angle of 20°. The stream flows generally along the strike of the beds for a distance of about a quarter of a mile, and large masses of stone can there be easily dislodged from the dip slope and searched for Eurypterid remains. The strata consist of hard blue and grey flaggy shales and mudstones with calcareous nodules. Like the concretions in

the fish-band, these calcareous nodules are sometimes arranged in lines, which partly envelope the organic remains. The following fossils were collected from an exposure on the right bank of the stream, about 400 yards west from Dunside:

Ceratiocaris papilio (Salt.)
Neolimulus falcatus (Woodw.)
Eurypterus lanceolatus (Salt.)
,, *obesus* (Woodw.)
,, *scorpioides* (Woodw.)
Pterygotus bilobus (Salt.)
,, ,, var. *accidens* (Woodw.)
Pterygotus bilobus var. *inornatus* (Woodw.)
,, *raniceps* (Woodw.)
Slimonia acuminata (Salt.)
Stylonurus Logani (Woodw.)
Lingula minima (Sow.)

In a small tributary of the Logan Water from the north, at a spot about 250 yards west from Dunside, these flaggy shales have yielded specimens of *Spirorbis Lewisi*, *Beyrichia Klædeni*, *Dictyocaris Slimoni*, *Pterygotus bilobus*, *Slimonia acuminata*, and *Platyschisma helicites*.

In like manner, in the Blackberry Burn, at a point about 100 yards up stream from the alluvial cone where it joins the Logan Water, the following forms have been obtained from these beds, viz.: *Dictyocaris Ramsayi*, *D. Slimoni*, *Pterygotus bilobus*, *Lingula cornea*, and *L. minima*. South-westwards along the strike, the members of this group are found in the Kip Burn, another tributary of the Logan Water from the north, where they have yielded examples of *Ceratiocaris stygius*, and *Pterygotus bilobus*.

On the south-west side of the county boundary, and close to the watershed, the representatives of this sub-division reappear near the head of the Leaze Burn, where they consist of blue-grey flaggy shales, dipping to the W.N.W. at angles varying from 20° to 30°, and are traversed by thin basalt dykes. Some of the seams freely yield fragments of Eurypterids, the following fossils having here been collected: *Beyrichia Klædeni*, *Ceratiocaris papilio*, *C. stygius*, *Pterygotus bilobus*, and *Slimonia acuminata*.

(5 and 6) Along the northern limit of the Upper Ludlow Rocks numerous excellent sections show the two highest sub-divisions (5e and 5f of Fig. 117) of the Ludlow strata that immediately underlie the Downtonian or passage beds. One of the best sections is in the Blackberry Burn, which joins the Logan Water about a mile and a quarter to the south-west of Dunside. Prominent among these upper beds, as developed in this stream, are certain blue, grey, and green shales, with sandy mudstones and greywackes occasionally weathering into a rusty colour, which constitute group 5. The distinctive palæontological feature of this sub-division is the abundance in it of *Platyschisma* (*Trochus*) *helicites*, which is here associated with *Spirorbis Lewisi*, *Beyrichia Klædeni*, *Modiolopsis Nilssoni*, and *Orthonota solenoides*.

Some of the same characteristic fossils are likewise found in tributaries of the Logan Water from the north, viz., in the Kip Burn and in a stream near Dunside. To the south-west of the

county boundary the members of this group reappear in the Leaze Burn, where they have furnished specimens of *Platyschisma helicites* and *Beyrichia Klædeni;* and still further to the south-west, in a dry gully about half a mile W.N.W. of Priesthills shepherd's house, the following organisms have been obtained: *Spirorbis Lewisi, Beyrichia Klædeni. Modiolopsis Nilssoni, Orthonota solenoides*, and *Platyschisma helicites.*

The most highly fossiliferous locality in the basin of the Greenock Water is to be found in a small streamlet about half a mile E.N.E. of Waterhead, in the Greenock Water, where the grey sandy greywackes and greenish shales dip towards the north-west at 20°, and yield the fossils given in the annexed list:

Spirorbis Lewisi (Sow.)
Beyrichia Klædeni (M'Coy.)
Dictyocaris sp.
Slimonia acuminata (Salt.)
Goniophora cymbæformis (Sow.)
Modiolopsis complanata (Sow.)
Modiolopsis Nilssoni (His.)
Orthonota impressa (Sow.)
,, *rotundata* (Sow.)
,, *solenoides* (Sow.)
Platyschisma helicites (Sow.).

In the prolongations of this group towards the south-west of the Greenock Water, some of the characteristic fossils have been found in the Lann Burn, about three-quarters of a mile to the south-west of Waterhead and in an adjoining streamlet.

The members of the highest sub-division of the Ludlow rocks, consist of green flaggy and sandy greywackes with partings of grey and red mudstones, that have hitherto proved unfossiliferous. Indeed, they merge gradually into the red and yellow sandstones which form the base of the overlying Downtonian series.

Downtonian Series.

On the north-west side of the arch of Wenlock and Ludlow rocks, in the Lesmahagow inlier, there is a broad area occupied by the overlying strata forming the Downtonian group. Indeed, over much of that region the beds lie at low angles, and sometimes form gentle undulations. In this respect the geological structure of the Downtonian area on the north-west side of the Lesmahagow inlier differs widely from that met with in the case of the Hagshaw anticline.

Though there are various sections showing the gradual sequence from the Upper Ludlow rocks into the conformable series of red and yellow sandstones, yet the local conglomerate (Sub-division 7) has nowhere been detected on the north-west limb of the Lesmahagow inlier. In the sequel we shall point out that it is typically developed in the Hagshaw anticline and near Carmichael Manse.

(8) *Red and Yellow Sandstones* (6b in Fig. 117).—Perhaps the finest section of the passage from the green flaggy and sandy greywackes (Upper Ludlow) into the overlying red and yellow false-bedded sandstone is to be seen in the Blackberry Burn—

a tributary of the Logan Water. At a point about half a mile up from the foot of the stream, the passage-beds consist of red mudstones and sandstones which dip towards W.N.W. at angles varying from 15° to 18°. They graduate downwards into the uppermost Ludlow group. Similar strata are observable near the junction of the Kip Burn, but the sequence is there disturbed by a normal fault trending E.N.E., by means of which the Downtonian beds are brought into conjunction with the underlying Ludlow rocks.

Still further to the south-west, in the Leaze Burn, one of the tributaries of the Dippal Burn, in the adjoining county of Ayr, the grey flaggy sandy greywackes (No. 6) pass upwards into red flaggy sandstones and shales which are inclined to the W.N.W. at angles varying from 10° to 20°. These are succeeded by false-bedded yellow sandstones, which are extremely friable, and likewise dip to the W.N.W. at an angle of about 10°, though in some instances gentle undulations are observable. In the Dippal Burn, above and below the mouth of the Leaze Burn, these yellow beds are admirably seen. Beyond the valley of the Dippal in the tributary which drains the hollow between Regal and Goodbush Hills, red sandstones are associated with the yellow beds.

(9) *The Fish-beds.*—The group of strata which includes the Downtonian fish-band (6c in Fig. 117) is well exposed in the lower reaches of the Dippal Burn, in the Slot Burn, and in various streamlets forming the sources of the Glengavel and Kype Waters. Its members, as there displayed, may be described as green and red mudstones, with bands of grey shale and greywacke in marked contrast to the underlying subdivision. Several small faults intervene which interrupt the natural sequence of the strata both in the Dippal Burn and some of its tributaries.

The fish-band, the most interesting feature of this group, comprises from twelve to fifteen feet of alternations of brown flaggy carbonaceous shales and green mudstones. No organic remains have hitherto been found in the mudstones; the fishes and eurypterids occur at various levels throughout the carbonaceous shales.

The Dippal Burn, from the shepherd's house at Dippal down to near its point of junction with the Slot Burn, displays an almost continuous section of these green mudstones and sandy greywackes, and has excavated a small gorge for a short distance through them. At a point about 350 yards up stream from the shepherd's house, on the south bank, an exposure of the fish band may be seen. Here the yellow sandstones are overlain by black carbonaceous sandstone, which is in turn succeeded by the green mudstones with brown flaggy carbonaceous shales containing ichthyolites. The thickness of the fish-band at this locality is not more than about four feet. Below the shepherd's house, green mudstones and greywackes, there exposed, lie not far from the horizon of the fish-band, for the latter reappears at a point about 200 yards up from the junction of the Dippal

Burn with the Greenock Water, where some of the characteristic fishes of the zone have been obtained, viz.: *Thelodus scoticus*, *Birkenia elegans*, *Lasanius problematicus*, *Ateleaspis tessellata*, together with a eurypterid.

Again, near the head of Dippal Burn, about half a mile to the south-east of the crest of Goodbush Hill, the fish-band is again met with, evidently occupying a geological position similar to that near the foot of the stream. The normal passage downwards into the yellow sandstones is, however, here concealed by a fault, which is probably the continuation of that already described as occurring in the Kip Burn. Where it crosses the Dippal Burn it is probably of no great magnitude. On the north side of this fault the green mudstones and fish-bearing shales, which are here thrown against the yellow sandstones, are about twelve feet thick. The fossils obtained from this exposure are given in the subjoined list:

Fucoid-like markings.
Pachytheca sp.
Parka, new sp.
Ceratiocaris sp.
Eurypterus dolichoschelus (Laurie.)
Lanarkia spinulosa (Traq.)
,, *horrida* (Traq.)
,, *spinosa* (Traq.)
Thelodus scoticus (Traq.)
Birkenia elegans (Traq.)

The various exposures of the fish-band just described occur along the south-east margin of the belt formed by the members of group 9. In the Slot Burn, one of the tributaries of the Greenock Water near Seggholm, an important outcrop of this fossiliferous zone lies considerably to the north. It may, nevertheless, be on the same horizon, for the beds are inclined at gentle angles, and in some cases are almost flat, while the outcrop of the fish-band is shifted by a normal fault. This view is strengthened by the fact that, on the crest at the watershed east of Seggholm, an outlier of the overlying quartzite conglomerate (group 10), appears about half a mile to the south of the normal outcrop of the band. The Slot Burn outcrop appears about 200 yards up stream from the house at Seggholm (now in ruins). Here the fish-band, comprising fifteen feet of fossiliferous mudstones, is visible on the right bank, where it forms a steep slope strewn with rocky debris. This is one of the two best localities for ichthyolites in the Downtonian series, for all the species determined by Dr. Traquair from this horizon have been obtained here, together with eurypterids. The fossils from this place so far as they have been named are given in the annexed list:

Plant stems.
Pachytheca sp.
Dictyocaris sp.
Sponge ?
Ceratiocaris laxa (Jones and Woodw.)
Eurypterus dolichoschelus (Laurie.)
Stylonurus ornatus (Laurie.)
Myriapod.
Lanarkia spinulosa (Traq.)
,, *horrida* (Traq.)
,, *spinosa* (Traq.)
Thelodus scoticus (Traq.)
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)
Ateleaspis tessellata (Traq.)

A short distance up the Slot Burn Mr. Tait recently detected a second fish-band on a slightly higher horizon, which yielded several species of fishes, together with a myriapod; and in a streamlet about half a mile to the south of this locality he also obtained specimens of *Glauconome* in sandy shale not far below the outcrop of the quartzite-conglomerate.

It is highly probable that other exposures of the fish-band may yet be found along the northern limb of the Lesmahagow inlier, as that region has not yet been thoroughly explored since the recent discovery of fish-remains.

(10) *Quartzite-Conglomerate.*—The outcrop of this remarkable conglomerate (6d in Fig. 117) follows a sinuous course through the moors from Middlefield Law, north-west of the Greenock Water in the county of Ayr to Townend on the Kype Water, south-west of Strathavon, in the county of Lanark, a distance of about ten miles. In this region, however, it is not so typically developed as in the anticline of the Hagshaw Hills, further to the south. In the Slot Burn, for instance, near Middlefield Law, it is only a few feet thick, though it still bears its peculiar features, viz., abundance of well-rounded blocks of quartzite. To the north, in the Powbrone Burn, it is represented by a yellowish ferruginous sandstone, in which are set a few pebbles of quartzite. Its presence can be traced by the number of its peculiar pebbles strewn over the moorlands between that stream and the Kype Water at Juan Hill, where it again attains a considerable thickness and is split up into two beds.

(11) *Chocolate-coloured Sandstones.*—Next in order chocolate-coloured sandstones (6e in Fig. 117), occupy a considerable area to the north of the outcrop of the quartzite-conglomerate, and require no special description beyond reference to the fact that they present the normal characters of the Lower Old Red Sandstone division. They underlie the greywacke-conglomerate, however, which, according to the classification adopted in these pages, may be taken as a convenient base to the Lower Old Red Sandstone. This conglomerate is well seen in the Cove Burn, one of the sources of the Avon Water, in the south-west corner of Sheet 23 of the Survey Map. Though it has not been traced across the northern part of the red sandstone area, its presence is indicated by numerous scattered pebbles of greywacke. Still further to the north-west, in the neighbourhood of Lanfine, remains of *Cephalaspis Lyelli* were found many years ago in the overlying red sandstones, which clearly belong to the beds that underlie the great series of Lower Old Red Sandstone volcanic rocks.

Having described in the foregoing paragraphs the relations of the Downtonian rocks along the north-west margin of the Lesmahagow Upper Silurian inlier, we may now refer to their development on the east and south-east sides of that tract, where, as already indicated, the Wenlock and Ludlow rocks are abruptly truncated by a normal fault that obscures the natural sequence from the Upper Ludlow to the Downtonian series. In

this area the various zones from the red and yellow sandstones (Group 8) to the greywacke-conglomerate, at the base of the Old Red Sandstone, are to be seen.

The best section occurs in the Birkenhead Burn, a tributary of the Logan Water which traverses all the important zones in the Downtonian series, save the local conglomerate at the base (Fig. 117). At the fault which brings the Downtonian rocks into contact with the *Ceratiocaris* beds (No. 3), red sandy mudstones extend for a short distance down stream, inclined to the E.N.E. at an angle of about 20°. These are followed by red sandstones and mudstones, and eventually by friable yellow sandstones, which are pierced by a mass of yellow felsite, and dip in a similar direction at angles varying from 40° to 50° From their lithological characters there can be no doubt that these beds belong to group 8, a conclusion which is confirmed by the fact that further down the stream the red mudstones pass upwards into the group of strata containing the fish-band. This group is admirably seen in the burn, at a point about a mile west of Birkenhead Farmhouse, where, on the north bank, it forms a cliff, partly covered with herbage, but laid bare for exploration at the mouth of a tributary rivulet. Like the beds in the Dippal Burn, the members of this group consist of alternations of green mudstones and brown carbonaceous fish-bearing shales, which dip to the E.N.E. at an angle of about 30°, and pass below a fine exposure of the quartzite-conglomerate (10).

By means of a small normal fault which crosses the Birkenhead Burn in an E.N.E. direction, the outcrops of the green mudstones, fish-bearing shales, and the overlying quartzite-conglomerate are shifted westwards on the south side of the stream. On that side the green mudstones and shales are more weathered than in the exposure on the north bank, and they more readily yield the characteristic fishes and eurypterids. They are inclined to the north-east at an angle of about 45°, and are there seen to rest on red sandy mudstones.

The total thickness of the fish-bearing band in Birkenhead Burn is about fifteen feet, which includes the associated layers of barren green mudstone. The lowest fossiliferous zone of carbonaceous shales is about a foot thick, while higher up the fish-bearing seams measure from one to six inches. The remarkable feature of this exposure is the constant association of the fish-fauna with eurypterids that are characteristic of the underlying Upper Ludlow rocks. The fossils obtained by the Geological Survey from this locality are given in the annexed list:

Plants.
Sponge.
Ceratiocaris sp.
Eurypterus sp.
Pterygotus bilobus? (Salt.)
Slimonia acuminata (Salt.)
Stylonurus sp.
Theelodus scoticus (Traq.)
Lanarkia horrida (Traq.)
,, *spinosa* (Traq.)
,, *spinulosa* (Traq.)
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)
Ateleaspis tessellata (Traq.)

Lower down the stream the quartzite-conglomerate and part of the underlying fish-band are together repeated by a strike fault with a downthrow to the east. Still further east red and grey friable sandstones (11), are followed by the greywacke conglomerate, which is visible near the foot of Birkenhead Burn, and passes under the red sandstones of Lower Old Red Sandstone age, which at Lesmahagow yield *Cephalaspis Lyelli.*

The section of Downtonian rocks in the Logan Water, though by no means continuous, resembles in some respects that in the Birkenhead Burn, for the group containing the fish-band, together with the overlying quartz-conglomerate, is repeated by means of a strike fault. Immediately to the east of the north and south fault that truncates the Ludlow rocks at Dunside, red sandstones and red sandy mudstones appear with a N.N.E. dip. About one-third of a mile to the east of the fault a small exposure of the quartzite-conglomerate protrudes through the drift to the north of the alluvium. A fault, though not visible, must intervene immediately to the east of this point, for the red mudstones reappear and are associated with red and grey flaggy shales. Further east, towards Achrobert, the Logan Water displays a fine development of the quartzite-conglomerate interbedded with sandstone, the strata dipping to the north-east at an angle of 15°. The pebbles of quartzite vary in size from a few inches to a foot across. A search has been made for ichthyolites in the grey shales associated with the green mudstones beneath the conglomerate at this locality, but without success. At the base of the conglomerate zone a sill of acid intrusive rock has been injected along the bedding planes. Another mass of igneous rock occurs to the east of this conglomerate, which is followed by the chocolate and grey sandstones below the greywacke-conglomerate.

Along the south-east side of the Wenlock and Ludlow rocks of the Lesmahagow inlier, the boundary-fault gradually increases in magnitude. Hence the observer finds, that southwards from the Birkenhead Burn to the Nethan Water and the Auchenstilloch Hills, higher sub-divisions of the Downtonian series successively come in contact with the Wenlock and Ludlow rocks. For example, in the Birkenhead Burn, as we have shown, the red sandstones and mudstones (8) appear next the fault, while to the south-west, in the Nethan Water, the quartzite-conglomerate (10) occupies that position, and near the Auchenstilloch Hills the overlying red sandstones (11) are in contact with the Wenlock rocks. Further to the south-west the Wenlock, Ludlow, and Downtonian strata are buried underneath the various sub-divisions of the Carboniferous system.

ii. HAGSHAW HILLS ANTICLINE.

To the south of the Carboniferous areas of Muirkirk, Glenbuck, and Bankend, the Ludlow and Downtonian rocks reappear along the anticline of the Hagshaw Hills, where the strata are

inclined at high angles and where, in consequence, the various zones follow each other in rapid succession. Though the beds on the southern limb of this fold are inverted, the anticlinal structure is well defined by means of the various bands of conglomerate which in that region are typically developed.

From the neighbourhood of Little Cairn Table (Sheet 15) north-eastwards by the Glenbuck reservoir to a point near the margin of the Carboniferous rocks at Douglas (Sheet 23), a distance of about five miles, the Ludlow beds can be traced below the Downtonian strata, in a belt which varies from a quarter to a third of a mile in breadth. Excellent transverse sections are to be found in the various streams that drain the southern slopes of the Hagshaw Hills, and also in the Ree Burn, that flows north to join the Douglas Water at Parishholm, south of the Glenbuck reservoir. Though some of the zones of the Lesmahagow inlier have been identified in the anticline of the Hagshaw Hills they have not been traced from end to end of the Silurian belt, which is largely due to the difficulty of obtaining the characteristic fossils. Only the northern limb of the arch of Wenlock and Ludlow rocks has here been preserved, as in the case of the Lesmahagow inlier; the southern limb having been abruptly truncated by a reversed fault, by means of which the strata have been made to over-ride successive zones of the inverted Downtonian beds (Fig. 118).

Wenlock and Ludlow Rocks.

For the purpose of this work it will be sufficient to refer to one or two typical sections showing the order of succession from the base of the Downtonian series in descending order.

Perhaps the best section occurs in the Ree Burn, south of the Glenbuck reservoir, where an almost continuous sequence of the Ludlow rocks is exposed. At a point in the Douglas Water about 250 yards east of the foot of the Ree Burn, the highest visible beds beneath the basal conglomerate of the Downtonian series consist of hard grey greywackes and grey-blue flaggy shales, dipping towards the north-west at an angle of 55°. Westwards, beyond a basalt dyke, blue and grey shales appear, inclined at a similar high angle, and yielding specimens of *Orthoceras*. A few yards up the Ree Burn, blue finely-bedded shales and flaggy greywackes have supplied specimens of *Ceratiocaris*, *Slimonia*, and *Beyrichia Kladeni*. Further south these beds are succeeded by flaggy shales, which contain in considerable abundance fine examples of *Orthoceras*, and are in turn underlain by greywackes and blue shales, which, near the fault, are shattered and folded, the dip in one or two instances being towards the south-east.

In the Podowrin Burn, which drains the south-west slope of Hagshaw Hill and joins the Douglas Water near Monksfoot, a good transverse section is obtained of the Ludlow rocks. Lithologically they resemble those just described as occurring in the

Ree Burn, and they likewise have a general dip to the north-west at angles of from 50° to 60°, though in a few instances they are inclined to the south-east. About midway between the south-east boundary fault and the upper limit of the Ludlow rocks certain beds have proved highly fossiliferous, which tends to encourage the hope that further investigation may trace some of the sub-divisions from end to end of the Hagshaw Hills anticline. The following species have been obtained from this locality:

Favosites asper (D'Orb.)
Lindstromia sp.
Glyptocrinus basalis (M'Coy.)
Crinoid stems.
Ceriopora sp.
Cornulites sp.
Beyrichia Klædeni (M'Coy.)
Ceratiocaris papilio (Salt.)
Calymene Blumenbachi (Brong.)
Encrinurus sp.
Illænus sp.
Proetus Stokesi (Murch.)
Slimonia acuminata (Salt.)
Athyris (*Glassia*) *compressa* (Sow.)
Orthis Bouchardi (Dav.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, *polygramma* (Sow.)
Strophomena (*Leptæna*) *rhomboidalis* (Wilck.)
Ctenodonta sp.
Orthonota sp.
Orthoceras angulatum (Wahl.)
,, small smooth sp.

It is not improbable that the beds containing this assemblage of fossils may belong to Group 2 of the succession in the Lesmahagow inlier, where a somewhat similar facies of organic remains has been obtained (p. 572).

Downtonian Series.

The groups of the Downtonian series are typically developed along the north side of the Hagshaw Hills anticline. Within a horizontal distance of three-quarters of a mile, the various sub-divisions from the local conglomerate at the base to the chocolate sandstones (11), which underlie the greywacke-conglomerate, can be examined. The relations of the Downtonian groups to the Ludlow and Wenlock strata of that region are illustrated by the accompanying horizontal section which is drawn across the south-western part of the arch from Parishholm Hill north-west by Glenbuck reservoir to Hareshaw Hill.

In the northern limb of the fold the basal conglomerate (6a) follows the Upper Ludlow rocks in normal sequence on the south side of the road at the south-west termination of the Glenbuck reservoir, where it is inclined to the north-west at an angle of 30°. Lithologically, it differs in a marked degree from the quartzite-conglomerate and greywacke-conglomerate that occupy higher horizons, inasmuch as it consists generally of small pebbles of Arenig volcanic rocks, radiolarian chert, and quartz, with an occasional small pebble of Silurian grit or greywacke. The matrix is composed of a greenish-grey friable grit, which readily decomposes.

Next in order come red and yellow sandstones (6b), visible on the west bank of the reservoir, and dipping in a similar direction

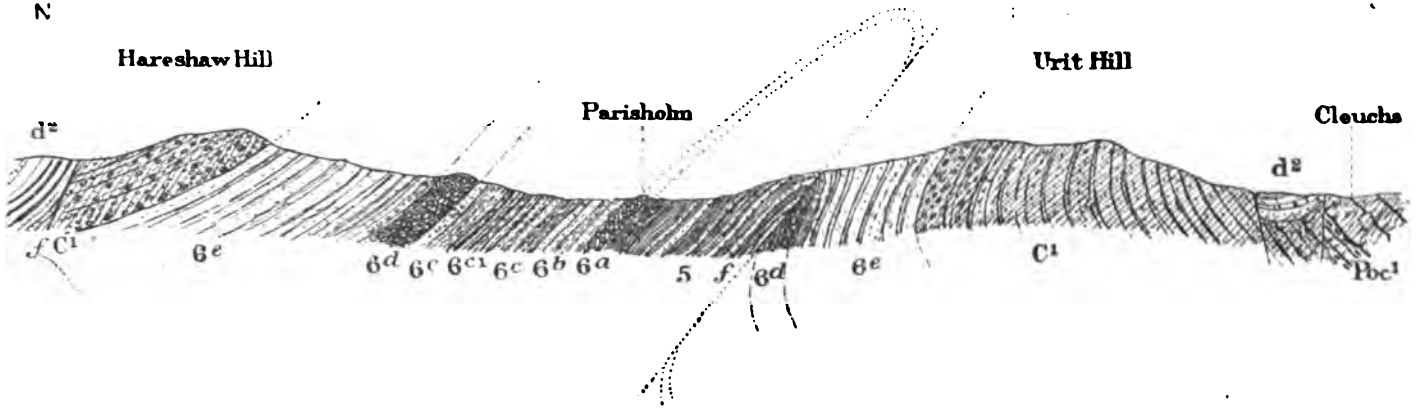


FIG. 118.—Section across the Hagshaw Upper Silurian Inlier through Parishholm, Douglas Water, Lanarkshire. (Length, three miles.)

d2. Lower Carboniferous.

C1. Lower Old Red Sandstone and conglomerate. PoC1. Volcanic rocks of Lower Old Red Sandstone age.

Downtonian { 6e. Chocolate-coloured sandstones. 6d. Quartzite-conglomerate. 6c1. Fish-band. 6c. Red and green mudstones (Fish-beds). 6b. Red and yellow sandstones. 6a. Conglomerate, with igneous pebbles.

5. Ludlow. f. Faults.

at angles varying from 30° to 40°. These correspond to Group 8 of the Lesmahagow inlier. The south-east side of the reservoir displays a fine development of the succeeding sub-division containing the fish-band (6c). Here red mudstones with green mudstones and brown carbonaceous shales, are inclined to the N.N.W. at angles varying from 45° to 50°. At a point where a small stream enters the reservoir, ichthyolites were exhumed from these shales, referrible to the genera *Lanarkia* and *Birkenia*. The fossiliferous zone is followed on the east bank of the reservoir by the quartzite-conglomerate (6d), which there attains a thickness of 100 feet, and presents its characteristic features, viz., the abundance and well rounded character of pebbles of quartzite derived from the Highlands. Next in order come the red and grey sandstones (6e), followed by the grey-wacke-conglomerate (C^1) of Hareshaw Hill. On the southern limb of the fold represented in Fig. 118, only the members of the highest group (6e) appear on the south side of the reversed fault. They consist of red and grey sandstones and dip generally to the north-west at angles varying from 45° to 50°.

The various sub-divisions of the Downtonian series can be traced along the north side of the Ludlow anticline of the Hagshaw Hills. During 1898, Mr. Tait proved the occurrence of the fish-band at three new localities—(1) in the Douglas Water south-west of Parishholm, (2) in the Monk's Water, and (3) in the Smithy Burn, north-east of Glenbuck reservoir. The fossils obtained from an exposure in a gully on the right bank of Monk's Water, about three-quarters of a mile south of Monkshead, are given in the subjoined list:

Sponge ?
Ceratiocaris ?
Eurypterus, small sp.
Scorpion.
Thelodus scoticus (Traq.)
Lanarkia spinosa (Traq.)
,, *spinulosa* (Traq.)
,, *horrida* (Traq.)
Birkenia elegans (Traq.)
Lasanius problematicus (Traq.)

At the top of the green mudstones (No. 9 of the Table, p. 569 and 6c of Fig. 118) Mr. Tait detected a brown sandy shale abundantly charged with *Glauconome*, together with *Spirorbis*, eurypterids, fishes and other organic remains. This zone overlies the fish-bearing bands, both in the Lesmahagow and Hagshaw Hills anticlines. The fossils given in the following list have been collected from the *Glauconome* band, in the Smithy Burn—the west branch of Podowrin Burn, that drains the south slope of Hagshaw Hill.

Pachytheca sp.
Sponge.
Glauconome disticha (Goldf.)
Eurypterus dolichoschelus (Laurie.)
Spirorbis sp.
Lasanius problematicus (Traq.)
Ateleaspis tessellata (Traq.)

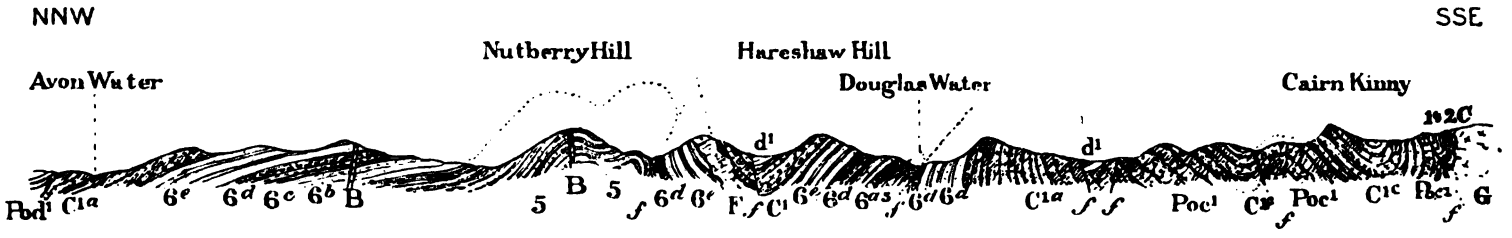
On the southern side of the Ludlow arch only the members of the highest sub-division (6e) of the Downtonian series can be traced from end to end of the area, being followed in normal

order by the greywacke-conglomerate. At one point, however, viz., in the Monk's Water, a small exposure of the quartzite-conglomerate can be seen in contact with the Wenlock and Ludlow rocks, the remainder of the outcrop being concealed by the reversed fault. It is worthy of note that the inversion of the Downtonian rocks is not persistent along the southern limb of the fold, for in the Monk's Water the sub-divisions of that series generally have a normal dip to the south-east.

iii. CARMICHAEL BURN INLIER.

To the north-east of the Carboniferous basin of the Douglas Water the Ludlow and Downtonian rocks reappear along an axial fold in the neighbourhood of Carmichael Manse, which, as already indicated, is probably a continuation of the arch of the Hagshaw Hills. The sections, however, are imperfect, much of the evidence being concealed by drift or alluvial deposits. In the Explanation descriptive of the area included in Sheet 23 of the one-inch Map of Scotland, reference is made to the occurrence of Upper Silurian fossils in certain beds, which, at that time, were believed to lie more than 5000 feet up from the base of the Lower Old Red Sandstone of this region. The discovery of these fossils was made by Sir A. Geikie in the course of the survey of that district. During the recent re-examination of the ground by the Geological Survey certain known stratigraphical horizons were detected which throw light on the geological structure.

The fossils occur in the Carmichael Burn, at a point about 250 yards south of the manse, and about 60 yards north from a bridge across the stream. Here, on the right bank, green mudstones appear with a dip to the north-west at angles varying from 45° to 50°, and have furnished specimens of *Monograptus*, *Beyrichia Kluedeni*, *Dithyrocaris striata*, and *Orthoceras dimidiatum*. These mudstones are immediately succeeded by a fine conglomerate, containing fragments of radiolarian chert and Arenig volcanic and plutonic rocks, which closely resembles in lithological characters the fine conglomerate that forms the base of the Downtonian series in the Hagshaw Hills and immediately overlies the Upper Ludlow beds. Indeed there can be little doubt that we have here the representatives of the Upper Ludlow rocks and the basal conglomerate of the Downtonian series, for further down the stream at a distance of 500 yards the quartzite-conglomerate (6d) is met with on the left bank. Owing to the depth of boulder clay no solid rock is visible between the two conglomerates, but, notwithstanding this fact, the petrological characters of the upper band are quite distinct. It contains well-rounded pebbles of quartzite, which are embedded in a sandy matrix, and dips to the north-west at an angle of 20°. When traced to the south-west this horizon reappears on the slope of Chapel Hill, where the rock merges into a conglomeratic sandstone and passes underneath chocolate sandstones.


NNW
SSE
Nutberry Hill
Hareshaw Hill
Avon Water
Douglas Water
Cairn Kinny
d1
d1
B
5
B
5
f
F.f
f
f

To the south of the exposure of Upper Ludlow mudstones in the Carmichael Burn, no solid rock is visible for a distance of upwards of half a mile, so that we have no evidence bearing on their relations to the strata in that direction. The latter consist of sandstones with conglomeratic bands, which are associated with the volcanic and plutonic rocks of Lower Old Red Sandstone age. It is highly probable, however, that in the Carmichael Burn area the geological relations of the Upper Ludlow and Downtonian rocks are identical with those which prevail in the Hagshaw Hills; or, in other words, that an arch of Ludlow and Downtonian rocks is there truncated by a reversed fault which may be the prolongation of that in the Hagshaw Hills.

iv. AREA SOUTH OF TINTO.

The south-east slope of Tinto displays a prominent exposure of the quartzite-conglomerate of the Downtonian series, at a point about a mile due north of the village of Wiston. In the fields to the north-west of Eastfield Farmhouse, the green mudstones and shales (Group 9), which elsewhere contain the Downtonian fish-band, are visible, while in the bed of the reservoir at the farm-steading hard greenish-grey greywackes and shales resembling the Ludlow rocks of Lanarkshire are met with. No organic remains have been obtained from these beds, but the zones of the Downtonian series are nevertheless quite recognisable. Their relations to the greywacke-conglomerate and the volcanic series of the Lower Old Red Sandstone have not been worked out in detail, but it seems clear that the greywackes and shales at Eastfield Farmhouse are faulted against the adjacent lavas of Lower Old Red Sandstone age which lie to the south.*

* During 1899 Mr. Tait obtained further organic remains from the Ludlow and Downtonian rocks of the Lesmahagow "inlier," regarding which Dr. Traquair has kindly supplied the following note:—

"Two additional specimens of *Lasanius*, collected by Mr. Tait at Seggholm since my notes at p. 567 were in type, indicate a new species distinguished from *L. problematicus* by the considerably greater proportional size and length of the spurs or thorns borne by the median scutes, and which I propose to designate *Lasanius armatus*. In one of these two examples, the rays of the acutely bilobate heterocercal tail are preserved, the arrangement of which furnishes the long-desired clue to the position of the median row of scutes, proving that they were placed along the ventral margin of the body. Consequently, it is now very improbable that the gridiron-like arrangement of ossicles in the anterior part of the body had anything to do with the support of the branchiæ.

"*Birkenia elegans* has now been found by Mr. Tait in the *Ceratiocaris* band (Ludlow) at a new locality, a few yards west of Shanks Castle, Logan Water."

CHAPTER XXV.

UPPER SILURIAN ROCKS NORTH OF THE TABLELAND —*continued.*

THE PENTLAND HILLS.

WITHIN the range of the Pentland Hills and completely surrounded by various sub-divisions of the Old Red Sandstone and some of the associated igneous rocks, four isolated patches of Upper Silurian strata have, at various localities, furnished a large and definite assemblage of organic remains. Though far removed from the Upper Silurian inliers near Lesmahagow they nevertheless have certain features in common, for here, as in Lanarkshire, an ascending series can be traced from the Upper Ludlow rocks into the Downtonian passage-beds, while some of the palæontological zones may be correlated in the two regions. But apart from these characteristics, considerable differences in the respective types of sedimentation were recognised by Salter in his Appendix to the Geological Survey Memoir on the Geology of the neighbourhood of Edinburgh.

In order to understand the complicated relations of the various patches of Upper Silurian strata to the younger Palæozoic rocks of the Pentland Hills, it is necessary to bear in mind that we have here three great divisions, which for some time have been regarded by the Geological Survey as belonging to the Old Red Sandstone. First, there is the series of passage beds (Downtonian) which rest conformably on the Upper Ludlow rocks and are composed of red and yellow sandstones, alternating with green and red mudstones and sandy greywackes, well displayed in the sections of the river Esk and the Lyne Water. Second, there is the volcanic series of the Lower Old Red Sandstone, which includes a great succession of lavas and tuffs underlain by red sandstones, shales, and conglomerates, the basal bed being a coarse conglomerate composed mainly of greywacke pebbles derived from the ancient Silurian Tableland.. While in Lanarkshire no unconformability has been traced between the Upper Silurian and Old Red Sandstone groups (p. 568), yet in the Pentland Hills this greywacke-conglomerate rests on the upturned edges of the Wenlock, Ludlow, and Downtonian or passage beds into the Lower Old Red Sandstone. This prominent discordance is well seen along the southern and part of the northern margins of the Silurian inlier between the Lyne Water and the river Esk. Third, there are the representatives of the Upper Old Red Sandstone, which are separated by a

marked unconformability from all older rocks; indeed, this discordance is so conspicuous on the northern slopes of the range that at Bavelaw Castle the red sandstones of this upper division repose immediately on the highly inclined Silurian series.

A study of the physical relations and distribution of the strata in the various Upper Silurian inliers in the Pentland Hills reveals the important fact that some of the graptolite zones which occur close to the North Esk reservoir reappear several miles to the north at Habbie's Howe and Bavelaw Castle. It is therefore apparent that during the interval represented by the unconformability between the Downtonian beds and the greywacke-conglomerate the Upper Silurian and Downtonian groups must together have been reduplicated by folds and subjected to prolonged denudation.

The various areas of Upper Silurian rocks in the Pentland Hills may be grouped as follows: (1) The tract on the south side of the watershed extending from the Lyne Water by the North Esk River to Green Law, a distance of three and a half miles; (2) the patch at Loganlee reservoir; (3) the Hare Hill and Bavelaw Castle inlier; (4) the patch in Bavelaw Burn near Craigenterrie, situated to the north-east of the Black Hill.

i. INLIER EXTENDING FROM THE LYNE WATER BY THE NORTH ESK TO GREEN LAW.

This patch of Upper Silurian strata, which occupies between two and three square miles of the hilly ground at the head of the North Esk and Lyne Water, is the largest and most important of the series; indeed, it is the only one in the Pentland Hills that shows the Downtonian passage beds in addition to the Wenlock and Ludlow rocks. The two main sections are those exposed in the North Esk and Lyne Water, the former showing a complete transverse section of the Wenlock, Ludlow, and portion of the Downtonian strata, while the latter traverses mainly the passage beds overlying the Ludlow rocks.

Wenlock and Ludlow Series.

In the chapter devoted to the History of Research among the Silurian rocks of the Pentland Hills reference has been made to the gradual development of our knowledge regarding the geological structure and palæontological sub-divisions of the district. It may be sufficient to recall the fact that the general order of succession in the North Esk as given by Sir A. Geikie in the Memoir on the Geology of the neighbourhood of Edinburgh has been confirmed by subsequent investigators. He showed that by traversing the Esk from Carlops northwards to the watershed, the observer crosses the series nearly at right angles to its strike, and that with the exception of certain minor folds an ascending succession is traceable from the green, grey, and reddish shales at the reservoir to the Downtonian or passage

beds near the watershed. The researches of various local observers, notably of Messrs. John Henderson and D. J. Brown, have proved the existence of certain palæontological zones, some of which yield a large assemblage of organic remains. Messrs. Henderson and Brown further showed that the Downtonian or passage beds at the head of the North Esk section are traceable across the hills in a south-west direction to the Lyne Water, suggesting at the same time, from the presence of marine fossils in the conformable red sandstone series, that the latter might belong to the Silurian instead of the Lower Old Red Sandstone system.*

Since the North Esk section was first mapped by the present Director-General of the Survey, the various palæontological zones, as indicated by Messrs. Henderson and Brown in their papers on the Silurian Rocks of the Pentland Hills (Trans. Edin. Geol. Soc., vol. i., pp. 23-33, pp. 266-272), have been examined by the Geological Survey, and a large suite of fossils has been gathered, which, together with some of the lists published by Messrs. Henderson, Brown, and others, are incorporated in the following descriptions (Fig. 120).

At the southern limit of the section, below the reservoir, the river and the adjoining rivulets have laid bare numerous exposures of green, grey, and reddish shales with occasional bands of grit, which dip sometimes towards the north-west and sometimes towards the south-east at angles varying from 50° to 75°. From certain seams below the reservoir the Geological Survey obtained specimens of *Monograptus*, *Nucleospira pisum*, *Cucullella* sp., while Messrs. Henderson and Brown have recorded the following additional forms: *Monograptus priodon*, *Retiolites geinitzianus*, *Glassia (Athyris) compressa*, and *Theca* sp. from a knob near the cottage at the reservoir (Band A). Northwards towards the northern side of the reservoir, strata of the same general type as those just described are well seen on the shore of the lake above the mouth of Gutterford Burn. Here occur zones of green and red lumpy shales, with occasional grit bands, containing abundant remains of *Dictyocaris Ramsayi* (Salt.), which are either vertical or inclined to the north-west at high angles. Similar strata appear in the North Esk as far as the quarries below the mouth of the second rivulet above the reservoir. On the right bank of the river, near the head of the reservoir, certain flaggy bands of sandy grit, east of an old quarry, yielded to the Geological Survey crinoid stems, *Dictyocaris Ramsayi*, *Orthonota*, and *Pterinea*; and to Messrs. Henderson and Brown *Glassia (Athyris) compressa* and *Bellerophon dilatatus*.

The Gutterford Burn—an important tributary of the Esk from the north-east—displays an admirable section of this series of shales, which has become widely known within recent years from the discovery by Mr. Henderson of certain seams, yielding new forms of eurypterids, described by Mr. Malcolm Laurie.

* Trans. Edin. Geol. Soc. Vol. i., p. 272.

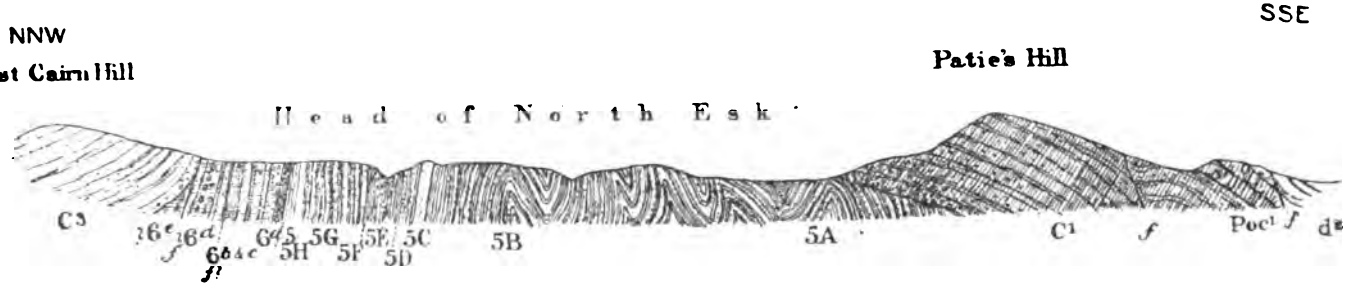


FIG. 120.—Section across the Upper Silurian Rocks of the Pentland Hills, exposed in the North Esk and its tributaries. (Length, two miles and a half.)

d2. Lower Carboniferous. C3. Upper Old Red Sandstone.

Lower Old Red Sandstone. PoC1. Andesites, etc. C1. Conglomerates, sandstones, etc.

6. Downtonian. 6e. Chocolate-coloured sandstone. 6d. Red sandstone, with large pebbles of quartzite. 6c. Red and green mudstones (Fish-bands). 6b. Red sandstones. 6a. Conglomerate, with igneous pebbles.

5. Wenlock and Ludlow. 5H. *Platyschisma* (*Trochus*) beds. 5G. Dark-brown sandy shales. 5F. Concretionary sandstone and shale, with *O. Maclareni*. 5E. Mudstones, etc., crowded with fossils. 5D. Greenish-grey shale and sandy bands. 5C. Conglomerate, grit, and sandstone. 5B. Sandstone and grit. 5A. Greywacke and shales.

These organic remains are associated with a few species of graptolites of characteristic Wenlock types, which leave no doubt as to the stratigraphical horizon of the beds. Of further interest is the occurrence of a thin band of coralline and encrinital limestone and certain beds containing well preserved remains of starfishes. The strata in the Gutterford Burn consist generally of green and grey shales with bands of micaceous flaggy greywacke and red and purple shale, which, from the constant change of dip, are apparently repeated by sharp folds. Indeed, throughout some parts of the section the dip is so persistently to the south-east that many of the outcrops may be inverted. Near the head of the stream, which is about a mile in length, green and buff-coloured mudstones alternate with green micaceous sandy flags and greywackes. At a point about twenty-five yards north from the ruin of Gutterford shepherd's house, on the east bank, the fossiliferous beds yield well-preserved specimens of starfishes. From the green and buff-coloured mudstones and shales the following specimens have been obtained: *

Monograptus vomerinus (Nich.)
Palæaster sp.
Cheirurus bimucronatus (Murch.)
Phacops Stokesi (M. Edw.)
Glassia (*Athyris*) *obovata* (Sow.)
Orthis sp.

The starfishes, however, occur in greater abundance in one of the green sandy bands, varying in thickness from a few inches to a foot and a half, which are associated with the mudstones. These have yielded specimens of *Ptilodictya*, *Monograptus vomerinus*, *Palæaster*, *Palasterina*, *Protaster*, and *Periechocrinus*.

About a quarter of a mile below the ruin of the shepherd's house the beds crop out which have yielded the new forms of eurypterids. The locality is about half a mile up the burn from the North Esk reservoir, where on the east bank the strata consist of flaggy micaceous greywackes, breaking with an irregular fracture and dipping towards the south-east at an angle of 80°. A characteristic feature of this eurypterid bed is the abundance on the divisional planes of that enigmatical fossil, *Dictyocaris Ramsayi*, forming, indeed, large black patches about an inch and a half across. Graptolites, though numbering few species, are not of infrequent occurrence, and considering the sandy nature of the material, are in fairly good preservation. The following list of organisms from this band is based partly on the researches of Mr. Malcolm Laurie, and partly on an examination of specimens in the Hardie collection determined by Mr. B. N. Peach:

Amphispongia sp.
Nidulites favus (Salt.)
Dictyonema venustum (Lapw.)
Dictyonema (*Chondrites*) *verisimile* (Salt.)
Cyrtograptus Murchisoni ? (Carr.)

* We beg to express our obligations to Dr. Traquair, F.R.S., for permission to examine the Hardie collection of fossils from the Upper Silurian Rocks of the Pentland Hills, now placed in the Museum of Science and Art, Edinburgh. This collection was made by the late Mr. Hardie, of Bavelaw, who, for many years, searched the Silurian Rocks of the Pentland Hills for eurypterids and starfishes.

Monograptus priodon (Bronn.)
,, *vomerinus* (Nich.)
Favosites sp.
Tentaculites tenuis (Sow.)
Palasterina sp.
Crinoid fragments.
Phacops sp.
Ceratiocaris sp.
Bembycosoma pomphicus (Laurie.)
Drepanopterus pentlandicus (Laurie.)
,, *bembycoides* (Laurie.)
,, *lobatus* (Laurie.)
Eurypterus conicus (Laurie.)
,, *minor* (Laurie.)
,, *scoticus* (Laurie.)
,, *cyclophthalmus* (Laurie.)
Eurypterus 3 sp. undetermined.
Stylonurus elegans (Laurie.)
,, *macrophthalmus* (Laurie.)
,, *ornatus* (Laurie.)
Slimonia dubia (Laurie.)
Dictyocaris Ramsayi (Salt.)
Palæophonus loudonensis (Laurie.)
Lingula Lewisi (Sow.)
,, *Symondsi* (Salt.)
Strophomena Walmstedti (Lindst.)
Euomphalus rugosus (Sow.)
Conularia monile (Lindst.)
,, *Sowerbyi* (Def.)
,, sp.
Orthoceras angulatum (Wahl.)
Gomphoceras ellipticum ? (M'Coy.)

Mr. Malcolm Laurie, who has described the *Arthropoda* from the locality just referred to in the Gutterford Burn, has kindly furnished the following note, giving the results of his researches:

"The zoological interest of the *Arthropoda* found in this deposit is very great. Notwithstanding the small exposure of the fossiliferous band, four genera, embracing ten species of *Eurypteridæ* have been collected. Two of the genera are peculiar to this horizon. The great variety of forms together with the high development of two of the species (*Stylonurus ornatus* and *Eurypterus scoticus*), occurring in this band—as yet the oldest from which specific forms have been obtained—shows that their first appearance must date further back than Wenlock time. While, however, certain forms are highly developed, the general facies of the remains as a whole is of an opposite character. *Slimonia dubia*, *Stylonurus macrophthalmus*, and *S. elegans* are all forms in which the generic characters are somewhat slightly developed. This is most marked in the limbs in the two species of *Stylonurus* and in the form of the body in *Slimonia*.

"The generalised aspect of this fauna is still better exemplified in the genus *Drepanopterus*, in which the most marked generic character is the absence of specialisation of the limbs. This is best seen in *D. bembycoides*, in which there is a gradual increase in the length of these organs from before backwards, but an entire absence of the differentiation of the posterior pair either into flattened 'swimming feet' as in *Eurypterus*, *Pterygotus*, and *Slimonia*, or into elongated crawling legs as in *Stylonurus*. Along with the absence of specialisation in the limbs, there is a conical form of body without any marked distinction between the mesosomatic and metasomatic regions. This unspecialised type of eurypterid is of great interest, especially as it is found in such a low stratigraphical horizon where it might naturally be expected to occur.

"The somewhat problematical form which I have described as *Bembycosoma pomphicus* may possibly be related to *Hemiaspis* rather than to the *Eurypteridæ*. If this be so, it is markedly

less highly developed as regards the form of the body than the typical *Hemiaspis*. In the latter there is a marked narrowing at the metasomatic region, whereas in *Bembycosoma* the body is conical.

"Perhaps the most interesting species from this deposit, however, is a Scorpion—*Palæophonus loudonensis*—described from one specimen which is in a bad state of preservation but shows the forward position of the eyes and the proportionately large *cheliceræ* characteristic of the genus. The point of the greatest morphological importance in this specimen is an indication of what may have been plate-like appendages on the mesosomatic segments. Should this interpretation of the obscure markings on these segments be correct it would imply either that this form was aquatic and furnished with gills, or, if terrestrial, that the original gill bearing appendages had not become completely fused with the abdomen to form an air chamber as in the recent forms.

"Looking at the fauna of this bed as a whole it may safely be said to have yielded more information of importance and interest concerning these fossil *arthropoda* than any other single deposit. This makes it the more to be regretted that it is now almost impossible to get further material from it.

"The species described from it are:

† *Palæophonus loudonensis* (Laurie.)
† *Slimonia dubia* (Laurie.)
* *Stylonurus macrophthalmus* (Laurie.)
* ,, *ornatus* (Laurie.)
† ,, *elegans* (Laurie.)
† *Drepanopterus lobatus* (Laurie.)
* ,, *pentlandicus* (Laurie.)
† *Drepanopterus bembycoides* (Laurie.)
† *Eurypterus scoticus* (Laurie.)
†· ,, *minor* (Laurie.)
* ,, *conicus* (Laurie.)
* ,, *cyclophthalmus* (Laurie.)
† *Bembycosoma pomphicus* (Laurie.)
Ceratiocaris sp."

About fifteen yards down stream from the eurypterid band a seam of limestone about ten inches thick lies embedded in mudstones, shales, and greywackes. Weathering with a rich brown colour, this rock in fresh fracture is found to be made up in large part of crinoid stems, while containing also remains of corals, brachiopods, and several other calcareous organisms. The species given in the annexed list have been determined from specimens in the Hardie collection obtained from this locality, together with specimens collected by the Geological Survey:

Nidulites favus (Salt,)
Dictyonema (*Chondrites*) *verisimile* (Salt.)
Monograptus priodon (Bronn.)
,, *vomerinus* (Nich.)
Cyrtograptus sp.
Ceriopora granulosa (Goldf.)
Ptilodictya sp.
Favosites gothlandicus (Fougt.)
,, *multiporus* (Lonsd.)
,, *asper* (D'Orb.)
Heliolites sp.
Cyathophyllum.
Ptychophyllum patellatum (M. Edw.)
Strombodes plicatus (Lonsd.)
Streptelasma (*Petraia*) *elongatum* (Phil.)
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
Orthis (*Dalmanella*) *elegantula* (Dalm.)
Atrypa reticularis (Linn.)
Strophomena (*Leptæna*) *rhomboidalis* (Wilck.)
Cyrtoceras sp.

* Trans. Roy. Soc. Edin., vol. xxxvii., p. 151. † Trans. Roy. Soc. Edin., vol. xxxix.

Returning now to the North Esk section, the observer finds in certain quarries near the second rivulet, about a third of a mile above the reservoir, a group of vertical strata, about 200 feet thick, which differ considerably in character from the great shaly division just described. They consist of hard sandstones and quartzose grits, which contain fossils, easily discernible on weathered surfaces, and in the centre of the quarry a shaly band yields specimens of *Orthonota amygdalina*. From these beds the following forms have been collected at various dates by the Geological Survey (Band B of A. Geikie, C of Henderson and Brown):

Crinoid stems.
Periechocrinus sp.
Glassia (*Athyris*) *compressa* (Sow.)
Atrypa reticularis (Linn.)
Orthonota (*Ctenodonta*) *thracioides* (Salt.)
Orthonota amygdalina (Sow.)
Platyschisma simulans (Salt.)
Mytilus mytilimeris (Conrad.)
Pterinea sp.
Holopella obsoleta (Sow.)

About half a mile to the south-west of this locality these arenaceous beds reappear near the head of Deerhope Burn, where they present similar characters and yield a similar assemblage of organic remains.

In the North Esk section the fossiliferous grits of the quarry above mentioned are succeeded by greenish-grey shales and sandy bands, which are highly fossiliferous. It was the large assemblage of organic remains from this horizon (Band D) which led Messrs. Henderson and Brown to the conclusion* that the rocks of Wenlock age occur in the Pentland Hills—an opinion which has been confirmed by Mr. Davidson in his memoir, "On the Upper Silurian Brachiopoda of the Pentland Hills." The forms given in the annexed list are taken from the papers published by Messrs. Henderson and Brown (Trans. Geol. Soc. Edin., pp. 31-33, p. 268, Band D):

Chætetes Fletcheri (M. Edw.)
Petraia subduplicata (M'Coy.)
,, sp.
Stenopora fibrosa (Goldf.)
Ceriopora granulosa (Goldf.)
Ptilodictya fucoides (M'Coy.)
Atrypa reticularis (Linn.)
Chonetes striatella (Dalm.)
Leptæna transversalis (Wahl.)
Lingula Lewisi (Sow.)
Meristella tumida (Dalm.)
Nucleospira pisum (Sow.)
Orbiculoidea Forbesi (Dav.)
Orthis biloba (Linn.)
,, *elegantula* (Dalm.)
,, *Lewisi* (Dav.)
,, *polygramma* (Sow.)
,, sp.
Strophomena antiquata (Sow.)
Strophomena applanata (Salt.)
,, *compressa* (Sow.)
,, *Hendersoni* (Dav.)
,, *pecten* (Linn.)
,, *rhomboidalis* (Wilck.)
,, *Walmstedti* (Lindst.)
Anodontopsis bulla (M'Coy.)
Ctenodonta 2 sp.
Cucullella antiqua (Sow.)?
Goniophora cymbæformis (Sow.)
Mytilus mytilimeris (Conrad.)
Orthonota amygdalina (Sow.)
,, *bulla* (Salt.)
,, *impressa* (Sow..)
,, *rigida* (Sow.)
,, *rotundata* (Sow.)
,, *truncata* (M'Coy.)
Pterinea asperula (M'Coy.)
,, *tenuistriata* (M'Coy.)

* Trans. of the Geol. Soc. Edin. Vol. i., p. 268.

Pterinea sp.
Bellerophon dilatatus (Sow.)
,, sp.
Cyclonema sp.
Euomphalus alatus (His.)
,, *funatus* (Sow.)
,, *rugosus* (Sow.)
,, *sculptus* (Sow.)
,, sp.
Holopella obsoleta (Sow.)
Loxonema elegans (M'Coy.)
Platyschisma simulans (Salt.)
Pleurotomaria sp.
Lituites sp.
Orthoceras excentricum (Sow.)
,, *angulatum* (Sow.)
,, 3 sp.
Phragmoceras compressum (Sow.)
Beyrichia Klædeni (M'Coy.)
Entomis impendens (Jones.)
,, *tuberosa* (Jones.)
Acidaspis Wrighti (Murch.)
Calymene Blumenbachi (Brong.)
Encrinurus sp.
Phacops Stokesi (M. Edw.)

Not far to the south-west of this outcrop of fossiliferous shales (Band D of Henderson and Brown) in the North Esk, an exposure of similar beds may be seen alongside of a footpath high up on the south slope of the tributary valley of Netherlaw Linn, whence the following fossils have been collected by the Geological Survey:

Plant.
Amphispongia oblonga (Salt.)
Coral.
Alveolites repens (Fougt.)
,, sp.
Favosites sp.
Petraia sp.
Heliolites sp.
Diastopora sp.
Ptilodictya sp.
Crinoid stems.
Turrilepas Wrighti (Woodw.)
Beyrichia impendens (Jones.)
Calymene Blumenbachi (Brong.)
Encrinurus punctatus (Brünn.)
,, sp.
Phacops Stokesi (M. Edw.)
,, sp.
Atrypa reticularis (Linn.)
Chonetes striatella (Dalm.)
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
Meristella MacLareni (Hasw.)
Nucleospira pisum (Sow.)
Orbiculoidea Forbesi (Dav.)
Orthis (*Bilobites*) *biloba* (Linn.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, *Lewisi* (Dav.)
,, *polygramma* (Sow.)
Crania (*Pholidops*) *implicata* (Sow.)
Rhynchonella nucula (Sow.)
,, *pentlandica* (Hasw.)
,, *Wilsoni* (Sow.)
Spirifera exporrecta (Wahl.)
Strophomena antiquata (Sow.)
,, *applanata* (Salt.)
,, *Hendersoni* (Dav.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
,, sp.
Whitfieldia (*Meristella*) *tumida*.
Anodontopsis bulla (M'Coy.)
,, *lucina* (Salt.)
Modiolopsis allied to *Chemnitzia*.
,, sp.
Orthonota Salteri (Eth. jun.)
,, sp.
Cardiola sp.
Ctenodonta sp.
Pterinea sp.
Bellerophon sp.
Cyclonema sp.
Euomphalus sculptus (Sow.)
Holopella obsoleta (Sow.)
Conularia sp.
Theca sp.
Orthoceras sp.

Still further towards the south-west the same band reappears near the head of the Deerhope Burn, where it has likewise furnished to the Geological Survey a large number of characteristic fossils.

In the Esk section, the beds of the succeeding zone (Band E of Henderson and Brown) are exposed at the mouth of the Wetherlaw Linn—a small tributary stream on the west side of

the valley—and also on the west bank of the Esk, a few yards to the north of that tributary. They consist of mudstones, shales, and sandy bands of a greenish-grey tint, and weather with a marked concretionary structure. In certain layers, they are crowded with casts of fossils, a characteristic form of one of the seams being *Leptæna transversalis*. From the scar on the west bank of the Esk, a few yards north of the Wetherlaw Linn Burn, the fossils given in the subjoined list were obtained by the Geological Survey:

Amphispongia oblonga (Salt.)
Sponge spicules.
Monograptus sp.
Favosites gothlandica (Fougt.)
Coral.
Ceriopora granulosa (Goldf.)
Diastopora sp.
Ptilodictya sp.
Turrilepas Wrighti (Woodw.)
Beyrichia (*Entomis*) *impendens* (Jones.)
,, *Klædeni* (M'Coy.)
,, (*Entomis*) *tuberosa* (Jones.)
Calymene Blumenbachi (Brong.)
Encrinurus punctatus (Brün.)
,, sp.
Phacops Stokesi (M. Edw.)
Atrypa reticularis (Linn.)
Chonetes.
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
Lunulicardium elegans (Salt.)
Orthis (*Dalmanella*) *elegantula* (Dalm.)
,, *Lewisi* (Dav.)
Orthis minuta (young of *S. pecten.*)
Rhynchonella pentlandica (Hasw.)
Strophomena antiquata (Sow.)
,, *applanata* (Salt.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
,, *Walmstedti* (Lindst.)
Anodontopsis lucina (Salt.)
,, *Salteri* (Eth.)
Ctenodonta obesa (Salt.)
Pterinea.
Bellerophon carinatus (Sow.)
Euomphalus funatus (Sow.)
,, sp.
Holopella obsoleta (Sow.)
Cyclonema.
Platyceras (*Acroculia*) *antiquatum* (Salt.)
,, *Gibbsi* (Eth. jun.)
Conularia Sowerbyi (Def.)
Theca sp.
Lituites sp.
Orthoceras sp.

The concretionary sandy mudstones just described preserve their highly fossiliferous character in the lower portion of the Wetherlaw Linn Burn; they likewise pass south-westwards across the head of Deerhope Burn, and are eventually overlapped by the greywacke-conglomerates and sandstones at the base of the volcanic zone of the Lower Old Red Sandstone.

Next in order in the Esk section, at a point about 150 yards north of Wetherlaw Linn, come concretionary greenish-brown sandstone and shales (Band F of Henderson and Brown), which furnish numerous and well-preserved specimens of *Orthoceras MacLareni*. In addition to this form, the Geological Survey has collected from it *Dictyonema* (*Chondrites*) *verisimile*, *Rhynchonella micula*, *Platyceras* (*Acroculia*) *antiquatum*, *Entomis tuberosa*, with a fragment of a crustacean; while Messrs. Henderson and Brown have obtained also *Crania* (*Pholidops*) *implicata*, *Spirifera* sp., *Pterinea retroflexa*, and *Conularia Sowerbyi*.

A little further north the Esk is joined from the west by the Henshaw Burn, in which, a few yards from its foot, yellowish brown sandy concretionary sparingly fossiliferous bands appear. These are rapidly succeeded by dark brown sandy shales yielding

a large assemblage of organic remains (Band H of Henderson and Brown); those given in the subjoined list have been here collected by the Geological Survey:

Dictyonema (*Chondrites*).
Athyris sp.
Meristella MacLareni (Haswell.)
Nucleospira pisum (Sow.)
Rhynchonella pentlandica (Hasw.)
Anodontopsis bulla (M'Coy.)
Cucullella antiqua (Jones.)
Nucula sp.
Holopella obsoleta (Sow.)
Platyceras (*Acroculia*) *antiquatum* (Salt.)
Platyceras Gibbsi (Eth. jun.) ?
Conularia Sowerbyi (De Franc.)
Orthoceras subundulatum (Portl.)
Encrinurus sp.
Pterygotus bilobus (Salt.)
Slimonia acuminata (Salt.)
Entomis tuberosa (Jones.)
Dictyocaris Ramsayi (Salt.)

The following additional forms have been recorded from this zone by Messrs. Henderson and Brown, viz.:

Antifopsis sp.
Beyrichia impendens (Jones.)
Cythere umbilicata (Jones.)
Leperditia umbonata.
Lingula lata (Sow.)
Cyrtia exporrecta (Wahl.)
Pterinea retroflexa (Wahl.)
Platyschisma simulans (Salt.)
Bellerophon expansus (Sow.)
Orthoceras gregarium (Sow.)

Among the noteworthy palæontological features of the zone are: (1) the great abundance of a new species of *Rhynchonella* discovered by the late Mr. Haswell and named by him *R. pentlandica*, and (2) the common occurrence of *Platyschisma simulans*. Indeed, in the North Esk section the members of this zone (Band H) lie not far beneath the Downtonian or passage beds, for they graduate upwards through some green sandy shales and soft red shales into a band of red conglomerate which here marks the base of the conformable red sandstone series. In the first edition of the Geological Survey Map of the Edinburgh region (Sheet 32), these soft red shales and conglomerates were correctly taken as indicating the base of the conformable red sandstone series, but in the sequel we shall show that Messrs. Henderson and Brown were likewise right in their contention that these red beds and the underlying Ludlow rocks are prolonged south-westwards to the Lyne Water, where they appear to the south of Hareshaw.

Downtonian Series.

The exposures of this overlying conformable series both in the North Esk and Henshaw Burn are by no means satisfactory, as the sections are not continuous, but taken in connection with the evidence furnished by the Lyne Water, the strata may be correlated in a general way with their probable equivalents in the Lesmahagow region. In the North Esk they consist of red and yellow sandstones, grits, and shales, which are exposed only at intervals in the stream northwards for a distance of about

300 yards. At their northern limit they are abruptly truncated by a fault which brings down against them the Upper Old Red Sandstone. In like manner, in the Henshaw Burn, similar red sandstones appear at intervals, and at one point near their northern limit a band of conglomerate with a few quartzite pebbles, recalls the quartzite-conglomerate that overlies the fish-bed in the Lesmahagow region. In these sections we fail to find the green shales and mudstones associated with the conformable red sandstones at Lesmahagow and in the Lyne Water. There are, however, numerous gaps where no strata are visible, so that these rocks might quite well occur in the North Esk section though not at present exposed there. The discovery by Messrs. Henderson and Brown of *Entomis tuberosa*, *Platyschisma helicites*, and fragments of an *Orthoceras* in certain yellow and red beds on the Deerhope Rig, at a point about 600 yards west from the foot of the Henshaw Burn, may be of importance, if these fossils really occur within the Red Sandstone series.

The section in the Lyne Water (Fig. 121) at the south-west limit of the Upper Silurian inlier of the Pentland Hills, lays open an important development of Upper Ludlow rocks. A small tributary which joins the Lyne from the east, at a point about 300 yards south of Hareshaw shepherd's house flows nearly parallel to the general strike of the Silurian strata, which here consist of green shales and mudstones, resembling the Upper Ludlow rocks of the North Esk. Along their southern limit they are faulted against the greywacke-conglomerate which forms the base of the sedimentary strata underlying the volcanic division of the Lower Old Red Sandstone. This dislocation is of no great amount, for the beds of conglomerate and sandstone are nearly flat or dip at a gentle angle to the south-east—that is, away from the Upper Silurian axis. But such as it is, the fault is seen in the Lyne Water below the foot of this tributary stream, and likewise in the south branch of that tributary. Towards the close of 1896 a careful search for fossils was made in the green shales and mudstones exposed in this burn, with the result that some of the characteristic forms of the Upper Ludlow rocks in the North Esk were obtained in considerable numbers, which, with others, are given in the accompanying list:

Turrilepas sp.
Beyrichia impendens (Jones.)
,, *Klœdeni* (M'Coy.)
Ceratiocaris Murchisoni (M'Coy.)
Rhynchonella pentlandica (Hasw.)
Grammysia rotundata (Sow.)
Mytilus mytilimeris (Conr.)
Bellerophon sp.
Chelodes sp.
Platyceras(*Acroculia*)*cornutum*(His.)
,, ,, *antiquatum* (Salt.)
Platyschisma simulans (Salt.)
Orthoceras MacLareni (Salt.)

In the Lyne Water at the junction of the two streams a small exposure of conglomerate may be seen, the relations of which are uncertain, but which is probably faulted against the Silurian rocks, for there is here evidence of much disturbance. Immediately to the north of this conglomerate the green shales and

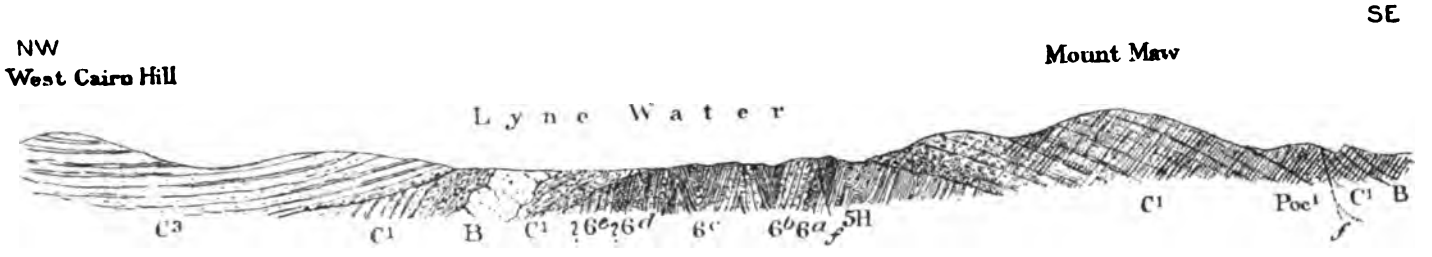


FIG. 121.—Section across the Upper Silurian Rocks of the Pentland Hills, exposed in the Lyne Water. (Length, four miles and a half.)

Upper Old Red Sandstone.	C3. Conglomerates and Sandstones.
Lower Old Red Sandstone.	C1. Conglomerate and sandstone. PoC1. Volcanic rocks.
6. Downtonian.	6e. Chocolate-coloured sandstone. 6d. Quartzite conglomerate. 6c. Red and green shales (fish beds). 6b. Red sandstones. 6a. Conglomerate, with igneous pebbles.
5. Ludlow .	5H. *Trochus-* (*Platyschisma-*) beds.
	B. Intrusive dolerite. f. Faults.

mudstones of Upper Ludlow age reappear, and have yielded the following forms:

Periechocrinus moniliformis (Mill.)
Crinoid stems.
Entomis sp.
Turrilepas Wrighti (Woodw.)
Ceratiocaris leptodactylus (M'Coy.)
,, *Murchisoni* (M'Coy.)
Orthonota solenoides.
Platyceras (*Acroculia*) *antiquatum* (Salt.)
Platyschisma simulans (Salt.)
Pleurotomaria helicina (Lindst.)
Tremanotus longitudinalis (Lindst.)
Orthoceras MacLareni (Salt.)

Northwards, at a prominent bend in the Lyne Water to the west, and about 270 yards south of Hareshaw shepherd's house, coarse conglomerate is met with, dipping towards the north-west at high angles. It contains large pebbles of porphyry and other rocks, but these are hardly distinctive enough to determine the precise geological horizon of this band. At the point where the Lyne leaves its east and west course and resumes its normal trend, this coarse conglomerate is bounded on the west side by a north and south fault, having a downthrow to the east, which brings it in contact with fine conglomerate and red sandstones, well seen on the west bank of the Lyne about 260 yards south of Hareshaw, where they are inclined to the north-west at high angles. These pebbly and sandy sediments are evidently the basement beds of the conformable red sandstone series (Downtonian). They are exposed at intervals in the bed of the Lyne Water northwards as far as the shepherd's house of Hareshaw, and are either vertical or inclined at high angles to the north-west.

Further up the same watercourse these conformable red sandstones are succeeded by green and blue shales and mudstones with bands of flaggy greywacke, which, at a bend in the stream one-third of a mile north of Hareshaw, have yielded fragments of *Dictyocaris*. From their lithological characters they are evidently the counterpart of the green and grey slaty shales which, in the Lanarkshire area, overlie the first zone of red sandstones and underlie the conglomerate so abundantly charged with quartzite pebbles. A careful search has here been made for the fish-band which is such a persistent horizon in the Lesmahagow region. During 1898, Mr. Tait detected a brown sandy shale, on both sides of the Lyne Water north of Hareshaw which yielded the fossils characteristic of the *Glauconome* zone in the Downtonian rocks of Lanarkshire. On the east bank of this stream, twenty yards north of the sheepfold, about one-third of a mile north of Hareshaw, this band yielded a sponge, *Glauconome*, *Spirorbis*, together with a fragment of *Ateleaspis tessellata*. Moreover, along the line of strike, about three-quarters of a mile north-east of the locality just referred to, the *Glauconome* band was noted in the Lynslie Burn.

Northwards, in the Lyne Water these green mudstones and shales are followed by red pebbly sandstones and shales with

sun-cracks, which extend up stream for a distance of a quarter of a mile, and can be followed along the strike to the north-east, for about half a mile to the Lynslie Burn. To the north of this narrow belt of red sandstones, green and red mudstones and shales again appear which are visible in the Lyne Water and in a tributary from the east, up to its junction with the Lynslie Burn. In the Lyne Water below the fork, these mudstones have yielded detached fragments of fishes, and near the foot of Lynslie Burn, close to the red sandstones, they furnished to Mr. Tait, a sponge (?), crinoid stems, *Spirorbis*, together with minute fragments, chiefly scutes, of the Downtonian fishes; *Birkenia elegans*, *Ateleaspis tessellata*, and *Lasanius problematicus*. The stratigraphical horizon of the more northerly belt of red sandstones is not quite clear; in the accompanying section (Fig. 121) it is represented as a repetition by folding of the sandstone belt south of Hareshaw.

The green mudstones and shales north of the second belt of red sandstones in the Lyne Water, in turn, are followed by red sandstones with red and green shaly partings and thin bands of conglomerate, that are covered unconformably by the greywacke-conglomerate and sandstones which form the base of the great volcanic series of Lower Old Red Sandstone age. It is of importance to note that in the Lyne section the quartzite-conglomerate which overlies the fish-band in Lanarkshire has not hitherto been observed.

From the evidence now advanced regarding the main Upper Silurian inlier of the Pentland Hills, we may draw the following conclusions:

(1) In the lower portion of the North Esk section, to the south and north of the reservoir, and especially in the Gutterford Burn, an important development of Wenlock rocks can be separated on palæontological grounds from younger strata.

(2) In the higher part of the North Esk, to the north of Wetherlaw Linn Burn, representatives of Ludlow rocks contain some of the characteristic fossils of the Upper Ludlow rocks of Lanarkshire.

(3) In the Esk section, and again in the Lyne Water, green shales and mudstones (Upper Ludlow) pass upwards into a comformable series of strata (Downtonian), composed of conglomerates with red sandstones and green and grey shales and greywackes, the latter yielding some organic remains found in the Wenlock and Ludlow rocks.

(4) Between the Wenlock, Ludlow, and Downtonian strata on the one hand, and the volcanic series of the Lower Old Red Sandstone on the other, there is here a complete discordance, for the conglomerates with greywacke pebbles, derived from the Silurian Tableland and forming the base of the volcanic series, rest on the upturned edges alike of Wenlock, Ludlow, and Downtonian strata.

ii. HABBIE'S HOWE INLIER.

The second tract of Upper Silurian strata, exposed at Habbie's Howe, near Loganlee reservoir, in the heart of the Pentland Hills, is of considerable interest from the occurrence in it of certain graptolites that help to define the geological horizon of the beds. The area is very limited, since it forms only a narrow lenticle, about three-quarters of a mile in length and a quarter of a mile in breadth. It is bounded on the south by a fault that brings the Upper Silurian strata in contact with the contemporaneous igneous rocks of Lower Old Red Sandstone age, while on the north side it is bounded by a mass of felsite belonging to the same period of volcanic activity.

Westwards from the Loganlee reservoir, the Silurian strata are exposed by the road-side, at a point about 250 yards from the lake, immediately to the west of a band of tuff, and they likewise appear at intervals for a distance of 200 yards up the valley. As a rule they are vertical or nearly so, and on the north-west side are faulted against the mass of acid intrusive rock just referred to. Towards the north-east they are visible on the hill slope, and likewise in a streamlet that empties into the reservoir. Their general inclination is towards the south-east at high angles. There is little variety in the character of the strata, as they consist mainly of grey slaty shales. Mr. Henderson found in them several species of graptolites, regarding which Professor Lapworth has made the following observations:*

"On the whole it may be asserted with safety that the researches of Mr. Henderson have furnished us with six distinct species of graptolites from the shales of Habbie's Howe, viz.: *Monograptus colonus*, *M. priodon*, *M. scoticus*, *M. Flemingi*, *Retiolites geinitzianus*, and *Dictyonema assimile*. The general facies of this group shows at a glance that the containing beds are of Upper Silurian age. The absence of *Monograptus Sedgwicki*, *M. Nilssoni*, and other peculiar Llandovery forms forbids us to place the beds in that formation, while the certain presence of *Monograptus priodon* and *Cyrtograptus scoticus*, which are unknown in the Ludlow, equally forbids us to assign them to that formation. They must, therefore, be considered as of Wenlock age. This result is in perfect harmony with that deducible from their stratigraphical position and from the fact of their great lithological resemblance to the neighbouring beds of the Esk reservoir, which are certainly of Wenlock age."

iii. BAVELAW CASTLE INLIER.

On the northern slope of the Pentland Hills, another Upper Silurian inlier is of triangular shape, and extends from the quarries at Bavelaw Castle to the western slope of Black Hill,

* Trans. Geol. Soc., Edin. Vol. II., p. 377.

including a portion of Hare Hill. In this small patch numerous rock-exposures are to be seen along its southern margin between Bavelaw Castle and the northern slope of Hare Hill. The strata present very uniform lithological characters consisting of zones of grey slaty shales, with sandy bands or flaggy greywackes and occasional grits. They resemble lithologically those in the lower part of the North Esk—a correlation which is supported by their palæontological evidence.

In the quarries at Bavelaw Castle, where the beds dip in different directions, sometimes to the south-east at 75° and sometimes to the north-west, the following fossils have been collected by the Geological Survey:

Glassia (*Athyris*) *compressa* (Sow.)
Lingula lata (Sow.)
,, *Lewisi* (Sow.)
Phacops sp.
Ctenodonta sp.
Euomphalus sp.
Pleurotomaria sp.
Theca sp.
Orthoceras sp.
Dictyocaris sp.

The slope of the range along the northern declivity of Hare Hill, exposes in many places grey slaty shales, sandy bands, and occasional grits, which are evidently repeated by folding, though their general dip is to the west or W.N.W. at angles varying from 40° to 65°. Two small ravines have laid open fossiliferous strata; the west ravine has furnished specimens of *Acidaspis*, *Glassia (Athyris) compressa*, *Meristella MacLareni*, *Cucullella* sp., *Theca*, *Orthoceras*; and the east ravine, *Monograptus*, *Retiolites geinitzianus*, *Dictyocaris*, *Lingula Lewisi*, and *Orthoceras*.

This palæontological evidence, while supporting the conclusion that the graptolite-bearing bands found near the north Esk reservoir, appear not only at Habbie's Howe but at Hare Hill on the northern slope of the Pentlands, serves to show that the Wenlock, Ludlow, and Downtonian rocks must together have been folded and extensively denuded before the advent of the volcanic period of the Lower Old Red Sandstone.

Special interest attaches to this inlier, from the fact that along its north-west and southern margins the Silurian strata are overlain unconformably by the red sandstones and breccia of Upper Old Red Sandstone age.

iv. CRAIGENTERRIE INLIER.

At the base of the northern slope of the Black Hill, and about a mile to the east of Threepmuir Quarry, the fourth Upper Silurian inlier may be seen. It forms a small triangular patch, which, on the west side, is covered unconformably by the Upper Old Red Sandstone, on the east side is faulted against the Lower Old Red Sandstone volcanic series, and on the south side is pierced by a mass of intrusive acid igneous rock. The slaty shales appear at the base of the northern declivity of Black Hill and at the source of a small burn that flows eastwards into

Threepmuir reservoir, but so far as known to us, no fossils have yet been obtained from them.

In connection with the Upper Silurian rocks of the Pentland Hills, reference ought to be made to the occurrence of numerous blocks of limestone in the greywacke conglomerate of Lower Old Red Sandstone age in the Logan Burn, about half a mile west of the Loganlee reservoir, which contain corals and other organisms, a large number of which are Upper Silurian forms. In all likelihood these blocks were obtained from bands of limestone similar to that in the Gutterford Burn, and occurring within the Silurian area of the Pentland Hills. The following list of fossils procured from these limestone-blocks includes forms collected by the Geological Survey, together with those in the Hardie collection:

Girvanella sp.
Crinoid stems.
Tetradium Peachi (Nich.)
Favosites gothlandica (Fougt.)
,, *Hisingeri* (Milne Edw.)
,, sp.
Plasmapora sp.
Halysites sp.
Heliolites sp.
Alveolites sp.
Ptilodictya sp.
Entomostraca.
Harpes ungula (?) (Barr.)
Calymene sp.
Phacops sp.
Lingula sp.
Cyrtia exporrecta (Wahl.)
Chonetes striatella (Dalm.)
,, sp.
Leptæna (*Plectambonites*) *transversalis* (Wahl.)
,, *sericea* (Sow.)
,, sp.
Orthis calligramma (Dalm.)
,, (*Dalmanella*) *elegantula* (Dalm.)
,, *rustica* (Sow.)
,, sp.
Atrypa reticularis (Linn.)
Strophomena imbrex (Pand.)
,, *pecten* (Linn.)
,, (*Leptæna*) *rhomboidalis* (Wilck.)
Rhynchonella Wilsoni (Sow.)
,, sp.
Spirifera elevata ? (Dalm.)
Cyclonema sp.
Orthoceras canaliculatum (Sow.)

CHAPTER XXVI.

THE GALLOWAY GRANITES AND ASSOCIATED IGNEOUS ROCKS.

GRANITE MASSES.

In the following descriptions the three main masses of granitic rock will be referred to as the Criffel mass, the Cairnsmore of Fleet mass, and the Loch Dee mass.

The general characters of the Criffel mass have already been described in the Memoir on Sheet 5, but in order to make clear its relation to the other masses it is desirable to repeat the descriptions already published.

Criffel and Dalbeattie Mass.—The prevailing type of rock in this mass is a moderately coarse-grained grey granite or quartz-diorite, essentially composed of biotite, hornblende, oligoclase, an alkali-felspar and quartz; iron-ores, apatite, and sphene are almost always present as accessory constituents, and a pale-coloured augite is occasionally found. The biotite is of the type usually occurring in granites. The basal plane is often well developed, but the prismatic planes are very imperfect, and it is rare to find a section showing even an approach to the hexagonal form. The pleochroism is very intense, varying from yellowish or reddish brown to nearly opaque. The first stage in the alteration of this mineral is seen in the replacement of the deep brown, characteristic of the β and γ axes, by a green colour, and this may occur without any change in the colour, for rays vibrating parallel to the α axis. The final stage of alteration, both in the biotite and hornblende, is the formation of chlorite and epidote.

The hornblende, like the biotite, is not markedly idiomorphic, though traces of the prismatic faces and the clino-pinacoid may occasionally be observed. The colour of the hornblende in the normal rock is green, but in the more basic modifications and in the dioritic inclusions, greenish-brown, and even brown varieties may sometimes be observed.

The dominant felspar in all the rocks, except those which represent the acid veins, is a plagioclase allied to oligoclase in composition. It is white in the hand specimen, and frequently shows a somewhat pearly lustre on the striated cleavage faces. Idiomorphism is a marked feature of the plagioclase, so that it evidently belongs to an early phase in the consolidation of the magma. A zonal structure may frequently be seen, and this is

most marked in the basic varieties of rock. The external portions of the zoned individuals are frequently more acid than the central parts, but there is no rigid law as to the increase of acidity from centre to margin. Narrow zones of a basic felspar may recur again and again in one and the same individual (6565).* Inclusions are comparatively rare in the plagioclase.

Both plagioclase and alkali-felspar become turbid by the development of minute flakes of a micaceous mineral.

The alkali-felspar contains both potash and soda, and is rich in the latter alkali. It never shows any trace of idiomorphism, but forms, together with quartz, the matrix or ground mass, if that term may be applied to a granitic rock, in which the other constituents are embedded. The extinction is often wanting in sharpness, and in a few cases microcline structure has been observed. The alkali-felspar may be easily distinguished from the oligoclase, when both are unaltered, by its lower refractive index and by the absence of crystalline form.

Quartz occurs in irregular grains and as ophitic patches. In the basic rocks, and in the inclusions, the interstitial character of the quartz is seen in the most marked manner; small patches wedged in between the idiomorphic constituents often extinguish simultaneously over a wide area. The mineral is rich in inclusions containing bubbles.

The accessory constituents do not require detailed description. The sphene is widespread, and may often be detected in the hand specimen. Under the microscope it is seen to be deeply coloured, pleochroic, and idiomorphic. It is very abundant in some of the inclusions. The augite deserves more than a passing mention. It is the pale-green or nearly colourless variety characteristic of the augite-granites, and usually occurs as a core in hornblende. In some of the more basic rocks it becomes sufficiently abundant to deserve recognition as an essential constituent.

Biotite, hornblende, augite, when present, and oligoclase, belong to the earlier phases of consolidation; quartz and alkali-felspar to the final stages. The relative proportions of the different constituents vary in different parts of the mass, and it is doubtful whether the prevailing type of rock is a hornblende-biotite-granite or a quartz-diorite of the tonalite-type. In any good exposure, such as that seen at the granite quarries near Dalbeattie, the normal granite or quartz-diorite is seen to contain basic inclusions, and to be traversed by acid veins. The basic inclusions, so far as they have been examined, always consist of a quartz-diorite richer in the minerals which belong to the earlier phases of consolidation, and poorer in quartz and alkali-felspar than the main mass of the rock. Sphene and apatite are especially abundant in many cases. The acid veins, on the other hand, consist almost entirely of quartz and alkali-felspar. The narrow veins are formed of a fine-grained aplite.

* The figures within brackets refer to the numbers of the microscopic sections in the collection of the Geological Survey.

but the broad veins assume the character of pegmatite, and frequently show the graphic intergrowth of quartz and felspar. These broad veins may sometimes be broken down the median plane, so as to disclose the presence of drusy or miarolitic cavities containing crystals of smoky quartz. A section through one of the pegmatitic veins in the Craignair Quarry (6596) shows the presence of a narrow band of nearly pure quartz running through the middle of the vein. The main mass of the vein is formed of quartz and alkali-felspar, sometimes intergrown so as to form a coarse variety of micro-pegmatite. Oligoclase and biotite occur as accessory constituents. The alkali-felspar occasionally shows the structure of micro-perthite, but microcline-structure is absent. The following table gives the specific gravity of each of the rocks occurring in the Craignair Quarry:

Acid vein, ...	2·60
Normal granite, ...	2·66
,, ,, ...	2·67
Basic inclusion.	2·77
,, ,, ...	2·71

So far we have been referring only to the massive rocks. As a type of the foliated rocks we may select a specimen from Criffel (1217). This is a medium-grained gneissose rock. The ferro-magnesian constituents form somewhat ill-defined flaser round phacoids of felspar or of quartz and felspar. Sphene is easily recognisable with a lens. Under the microscope the essential constituents are seen to be biotite, hornblende, oligoclase, alkali-felspar, and quartz. A pale-green augite (·4mm.) occurs as a core in one of the patches of hornblende. Brown idiomorphic sphene occurs in crystals of considerable size (·3 to ·75mm.). The alkali-felspar shows occasionally a distinct microcline-structure, and contains inclusions of oligoclase and quartz. Small patches of felspar, intergrown with vermicular quartz, are present, and also one or two grains of a mineral somewhat doubtfully referred to orthite. The interstitial movement which has resulted in the production of foliation, and which is proved by the field evidence to have been produced by earth stresses operating after the rock had reached its present position, and after the formation of the acid veins, has not affected all the constituents alike. The quartz and alkali-felspar, which, as we have already seen, were the last constituents to solidify, are those which have yielded most to the deforming stresses. They show signs of crushing, and frequently pass into thin micro-crystalline or even crypto-crystalline streaks, which wind round the comparatively uncrushed crystals of oligoclase. The distribution of the ferro-magnesian constituents has been modified by the movement. Instead of being irregularly distributed through the rock they tend to form flaser in association with the micro-crystalline aggregate of quartz and alkali-felspar. The oligoclase has been little, if at all, affected by the movement. These facts clearly

prove that the minerals which yield most readily to the deforming forces are those which consolidate last. It is highly probable that the pressure acted before the rock-mass had actually cooled. (See Plate XXIV., Fig. 2.)

Two specimens taken from a large block occurring about half a mile north by east of Kells Farmhouse near Southwick (6572 and 6573) represent the effects of deformation in a more extreme form. The rock loses the gneissose character, and finally passes into a grey granulite. The secondary micro-crystalline aggregate forms a much larger proportion of the main mass of these rocks, and cataclastic structures are strongly marked.

The foliation not only affects the normal hornblende-granite or quartz-biotite-diorite, but also the veins of aplite and the basic inclusions, which are exceptionally abundant near the junction (6576, 6589, and 6574). Even the quartz veins are foliated (6575). In all cases the foliation maintains the same general direction. The foliated veins of aplite are largely composed of the secondary micro-crystalline aggregate of quartz and felspar, and the large irregular grains of alkali-felspar, which have escaped crushing, show strain-phenomena under crossed nicols. The fact that the foliation in these veins has no reference whatever to the direction which they take is a striking proof that it cannot be due to fluxional movement during intrusion. It must be the result of dynamic forces operating after the intrusion of the granite and after the formation of the veins. A section, prepared from a specimen collected at a point about a quarter of a mile north of Kells Farmhouse (6589), has been cut through the junction of an acid vein with the normal granite. The junction line is nearly at right angles to the direction of foliation, which is seen to pass from one rock to the other without a break.

The principal portion of the Criffel mass is a tonalite rather than a true granite, but in view of the fact that it is identical in general appearance with a typical grey granite, it has been considered undesirable to change the name by which it has always been known. A special feature of this mass is the extraordinary abundance of sphene. It is rare to find a hand specimen in which the characteristic clove-brown crystals of this mineral may not be detected with a pocket lens.

If we were to follow the geographical order from south to north the Cairnsmore of Fleet mass would next engage our attention, but as the Loch Dee mass occupies petrographically an intermediate position it will be more convenient to take it next.

The dominant rock, as in the case of the Criffel mass, is a moderately coarse-grained grey granite. Biotite and hornblende are the principal ferro-magnesian constituents, and they vary in amount in different specimens. Plagioclase, alkali-felspar, and quartz occur, and bear the same structural relations to each other as in the Criffel mass. Taking the mass as a whole, the ferro-magnesian minerals and plagioclase are less abundant than they are in the Criffel mass. Nevertheless it is

possible to obtain specimens from many localities which are identical with the rock of Criffel, except in one respect. The sphene, which is such a marked feature in the southern mass, is here comparatively rare. Another feature which tends to give the Loch Dee granite mass a more or less distinctive character is the frequent absence of hornblende over considerable areas. As hornblende disappears the rocks become lighter in colour, and alkali-felspar and quartz increase relatively to the plagioclase. Moreover, the alkali-felspar passes through the stage of moiré-orthoclase to typical microcline. The dominant rocks of the Loch Dee mass may therefore be classed as quartz-diorite of the tonalite type, hornblende-biotite-granites, or hornblende-granitites and biotite-granite or granitites. These different varieties shade into each other by imperceptible gradations, and the alkali-felspar and quartz always belong to the later phases of consolidation, even when the former are developed as large pseudo-porphyritic crystals, which is sometimes the case.

Typical quartz-diorite (tonalite) occurs at White Laggan (214, 215), south of Loch Dee, near the southern end of the mass, and south of Craiglea Hill, near the head of Loch Doon, at the northern end of the mass. Hornblende-granitites, in which, however, plagioclase is generally the dominating felspar, occur at the Glenhead Lochs, N.N.W. of Loch Dee (7033), at the south-west end of Loch Enoch (2522), at Craignaw, 2½ miles north of Loch Dee (7035), at Craigeazle Hill, two miles E.N.E. of Loch Dee (7032), at the foot of Polmeadow Burn, four and a half miles west by north of Carsphairn, and near Portmark on Loch Doon. Biotite-granites or granitites occur in Glenhead Burn, west of Loch Dee (722), in the Kirreoch Burn, 5½ miles south-west of Carsphairn (690), on the hill-top N.N.W. of Craigrarson, six miles south-west of Carsphairn (697), at Lochhead, five miles west of Carsphairn (687), on the hill slope west of Slaethornrig, five miles south-west of Loch Doon Head (2535), at Loch Cornish, 5½ miles west of Loch Doon Head (714), and on Craignaw, east of Loch Neldricken (2523).

The last-mentioned rock is a typical biotite-granite, with pseudo-porphyritic crystals of microcline, and as it departs widely from the tonalite-type, which is so extensively developed both in the Criffel and Loch Dee areas, a detailed description of it may be given. It is a light grey rock with a faint tinge of pink. Biotite is comparatively rare; quartz is abundant and shows traces of idiomorphism; pseudo-porphyritic crystals of alkali-felspar, having a pearly lustre on their cleavage planes and measuring a quarter of an inch across, are fairly numerous. Under the microscope the essential constituents are seen to be biotite, oligoclase, microcline and quartz. The biotite is of the type characteristic of granitites. The oligoclase shows the usual tendency to idiomorphism, but it occasionally contains inclusions of quartz. The alkali-felspar occurs in large patches with irregular borders. It is a typical microcline with laminæ of plagioclase (oligoclase-albite) and inclusions of oligoclase, quartz, and biotite. Twin-

ning on the Carlsbad plan is common, so that the patches divide under crossed nicols into two halves. The quartz, which is very abundant, occurs in large grains, as granular aggregates and as rounded blebs. The large grains occasionally show traces of idiomorphism. The small rounded grains are found as inclusions both in the microcline and in the oligoclase.

A second specimen from the same locality (7035), already referred to in the list of hornblende-granites, deserves mention in this connection, as it connects the above rock with the more basic granites which constitute the greater portion of the Loch Dee mass. This is a normal grey granite in appearance, containing a few crystals of pseudo-porphyritic felspar, which, however, do not stand out prominently from the other portions of the rock. Under the microscope the main differences between this rock and the one just described are seen to be due to the greater abundance of biotite and the presence of hornblende in the former rock. Both contain microcline under the same conditions and in considerable quantity. The normal hornblende-granitites and tonalites contain only a very small proportion of interstitial alkali-felspar. As these merge into the biotite-granites the amount of alkali-felspar and quartz increases, and the hornblende disappears. Moreover, the alkali-felspar, which is present as a soda-orthoclase in the tonalites, is replaced by moiré-orthoclase, and finally by microcline-microperthite. The evidence furnished by the Loch Dee mass of the gradual passage from tonalite to granitite with microcline is of great importance, as serving to connect together the three large granitic areas of the Galloway district; for the latter rock, which is rare or absent from the Criffel mass and forms a subordinate part of the Loch Dee mass, is the dominant type of the Cairnsmore of Fleet mass. There can be no doubt that all three masses belong to the same petrographical province, and it is highly probable that the differences observed between the different masses are due to differentiation in the subterranean magma-basin, and that the differences observable in one and the same mass are in part at least due to differentiation *in situ*.

So far we have been referring to the dominant types of rock occurring in the Loch Dee area. There are, however, some subordinate masses of great interest. In the description of the Criffel mass it was pointed out that a pale-coloured augite sometimes occurs as an accessory constituent in the hornblende-granitite and quartz-diorite, and is occasionally present in sufficient quantity to deserve recognition as an essential constituent, thus giving rise to quartz-augite-diorites. Examples of quartz-augite-diorite may be obtained on the west slope of Ben Gairn, five miles south of Castle Douglas (1220), and at a point two-thirds of a mile east by north of Ben Gairn (6568). In the last-mentioned locality it forms part of a basic mass which occurs at the contact of the main mass with the Silurian sediments.

Similar rocks occur in the Loch Dee mass, and also in the small mass at Burnhead, which may be regarded as subsidiary

to that of Loch Dee. Here, however, they are associated with a rock hitherto unrecognised in the Criffel area, for which the term hyperite is proposed. This term was employed by Törneböhm in his well-known paper, Ueber die wichtigeren Diabas und Gabbro-Gesteine Schwedens (Neues Jahr, 1877, p. 377), for a rock of the gabbro family in which both hypersthene and augite (diallage) occur either with or without olivine. The essential constituents of these Swedish rocks are plagioclase, augite, hypersthene, titaniferous iron-ore, and apatite. Quartz and probably also orthoclase occur as interstitial matter. When olivine is present the rock is termed olivine-hyperite. Many subsequent writers have ignored the term hyperite in favour of norite, which, however, may be more appropriately applied to rocks devoid of augite or possessing it only in very small quantity. The typical Swedish hyperites are evidently more basic than the rocks we are now concerned with, but as they resemble them in containing both hypersthene and augite in nearly equal proportions, and also in other respects, to which reference will be made in the sequel, it seems desirable rather to extend the use of the old term than to invent a new one.

Hyperites (see Plate XXV., fig. 1) occur in direct association with the Loch Dee mass on the north face of White Laggan Hill (2521), south of Ballochbeattie, 4½ miles west of Loch Doon Head (709,2539,2540), on the hill-face west of Tunskeen, five miles south-west of Loch Doon Head (712), and on Craignasheenie Hill, five miles west by south of Loch Doon Head (2541). They are all dark-coloured medium to coarse-grained massive rocks, essentially composed of plagioclase, hypersthene (enstatite), augite, and biotite. Quartz and orthoclase occur as interstitial matter in all the more granitoid members of the group. Hornblende and iron-ores are present as accessories. The plagioclase has been definitely determined to be labradorite in one case, and it is probable that this is the dominant felspar; but as zonal structure is not infrequent, it is evident that the plagioclase is not always uniform in composition. In many specimens the mineral is crowded with minute opaque inclusions, which give a cloudy appearance to the thin sections when viewed with low powers. Idiomorphism is more marked than it is in typical rocks of the gabbro family. The sections in the more granitoid specimens are usually in the form of broad laths, but the boundaries are rarely straight lines, and contiguous individuals interfere with each other. In some specimens there is a decided tendency to a porphyritic structure, and two generations of plagioclase differing in size may be observed. The sections frequently show the presence of twinning on the Carlsbad and albite types, but pericline twinning has not been observed.

The rhombic pyroxene occurs as grains, as prisms with more or less rounded angles, and, more rarely, as fairly idiomorphic crystals. Two or more individuals frequently occur together, forming a polysynthetic group. The intensity of the pleochroism varies in different specimens. Inclusions of brown plates, similar

to those which occur in the well-known paulite variety, have been observed in one or two cases. The individuals sometimes have a narrow irregular edging of green hornblende.

The monoclinic augite occurs as grains, imperfect crystals, and polysynthetic aggregates. It is nearly colourless in thin section, and is usually free from inclusions. Sometimes, however, it contains the brown plates which are characteristic of some varieties of diallage.

Biotite is a constant feature of the hyperites, and is often as abundant as either of the other two ferro-magnesian constituents. It occurs in ragged plates, which are very strongly pleochroic, and which usually contain iron-ores and sometimes also augite and hypersthene as inclusions. Hornblende is present only as an accessory in the typical hyperite. It occurs as a narrow irregular fringe in association with both the rhombic and monoclinic pyroxenes.

Orthoclase may be clearly recognised in many of the sections, and is probably present in all. It forms, together with quartz, the matrix, so to speak, in which the other constituents are embedded, and therefore occupies the same position in the hyperites as it does in the tonalites and hornblende-granites. It occurs in the form of large irregular plates and as granular aggregates. A special feature of many specimens is the presence in the orthoclase of an extraordinary number of long acicular prisms of a perfectly colourless mineral, which appear to possess a lower refractive index than apatite. Quartz may generally be recognised, but is not abundant. It occurs as grains and interstitial patches. A small patch of micro-pegmatite was observed in one slide, but this substance is evidently very rare. The point is one of some interest, because the "norites" of Klausen in the Tyrol, described by Teller and Von John (Jahrb. d.k.k Geol. Reichsanstalt, 1882, p. 499), have many points in common with the rocks under consideration. The occurrence of micro-pegmatite is a common feature. In his descriptions of the Swedish hyperites, Törnebohm refers to the presence of quartz and probably orthoclase, and regards them as the latest products of consolidation. There can be no doubt that both these minerals are present in the hyperites associated with the Loch Dee mass, and that they occupy in relation to the other constituents the position assigned to them by Törnebohm. This feature, and the occurrence of the minute inclusions in the plagioclase, are subsidiary points which serve to connect the rocks under consideration with the Swedish hyperites.

We have now to consider the connection between these rocks and the more common quartz-diorites (tonalites) and hornblende-granitites. Evidence on this point is furnished by specimens from White Laggan Hill, one mile south-west of Loch Dee, and from the small detached mass of Burnhead. In both localities we find biotite-hyperites associated with quartz-augite-diorites, that is with rocks which are intermediate between the ordinary quartz-diorites and the hyperites. The presence of augite as an

accessory constituent, both in the Criffel and Loch Dee masses, has already been referred to. By an increase in the amount of this augite and a corresponding diminution in the quantity of hornblende, the quartz-diorites pass into quartz-augite-diorites, and by a further modification of the same kind, coupled with the introduction of a rhombic pyroxene, we have a gradual passage from the quartz-augite-diorites into the biotite-hyperites. These biotite-hyperites, therefore, represent the most basic phases of the granitic magma known to us at present. If subsequent research should bring to light still more basic rocks they will doubtless be found to consist of norites and gabbros.

The association of basic rocks containing rhombic and monoclinic pyroxenes with quartz-augite-diorites (augite-tonalites), quartz-diorites (tonalites), and biotite-granites (granitites), has been already noticed in other areas. Thus Lossen* has described such an association in the Brocken mass in the Hartz. The normal biotite-granite which forms the main mass of the Brocken sometimes contains augite as an accessory constituent, and these augite-granitites pass over into augite-biotite-quartz-diorites, and even into acid gabbro (biotite-augite-gabbro). In some of these more basic phases a rhombic pyroxene occurs.

Similar phenomena are recorded by Teller and Von John in the paper already cited. These authors point out that the intrusive rocks of the Klausen district do not readily group themselves under a collective name. They form rather a connected series, having at the one end quartz-mica-diorite, and at the other end a "norite" containing both monoclinic and rhombic pyroxenes. The two extremes are connected together by augite-bearing quartz-diorites and quartz-bearing enstatite-augite-plagioclase rocks ("quartz-norites").

This definite association of similar petrological types in widely separated districts, and in rocks of different geological age,† clearly points to the conclusion that plutonic rocks, like minerals, are subject to laws of paragenesis. It is opposed to the idea which has recently been resuscitated in France that the granites have largely assimilated the sedimentary rocks into which they have been intruded, but is in accord with the differentiation hypothesis.

We have now to refer to some subsidiary rocks which are more acid than the main mass. They are light in colour, comparatively free from ferro-magnesian constituents, and sometimes contain muscovite. They occur as apophyses of the main mass, and may be well observed on the southern slopes of Craigrarson, where the Silurian grits and greywackes have been largely recrystallised under the influence of the hydro-thermal agencies consequent on the intrusion of the granite. A junction specimen (2533) shows the contact of a medium-grained light-coloured aplite, containing muscovite, with a somewhat finer-grained biotite-hornfels. A few flakes of biotite occur in the aplite, but

* Jahrb. d. k. Preuss. Landesanstalt, 1887, p. xxvii.; 1890, p. xxv.; 1891, p. xxix.

† The Galloway granites are post-Silurian and pre-Carboniferous; the Brocken granite is post-Carboniferous.

some, if not all, of these appear to be of the nature of inclusions, and to belong really to the metamorphic rock. The contact rock is composed of quartz, turbid and altered felspar, and the characteristic brown mica, which forms aggregates between the larger grains of quartz and felspar. The aplite is a medium-grained rock essentially made up of orthoclase, quartz, and white mica, with a certain amount of oligoclase. Small patches resembling the contact rock in structure and containing biotite occur in the aplite. These patches are not sharply defined from the igneous rock, and they point to the conclusion that to a small extent the igneous magma may have incorporated and even assimilated portions of the surrounding rocks. M. Michel Lévy, in his memoir entitled "Contribution à l'étude du granite de Flamanville et des granites Français en général,"* and elsewhere, has called attention to facts of the kind here referred to, and has been led to the conclusion that they represent on a small scale phenomena which may take place on a large scale in deeper zones in the earth's crust. Without entering into a discussion on this question, we may remark that, so far as the granites of Galloway are concerned, phenomena of this kind are certainly local and unimportant.

In some cases the more acid veins pass into coarse-grained pegmatites. A second specimen, also taken from the slopes of Craigrarson, on the south side of the Kirreoch Burn (7028), serves to illustrate this point. One portion of the specimen is a medium-grained granite containing very little biotite; the other portion is a coarse-grained pegmatitic phase of the same magma. There is no sharp line of demarcation between the two varieties of rock. Under the microscope quartz and orthoclase are seen to be the two principal constituents, with oligoclase and biotite as comparatively unimportant accessories. The orthoclase shows traces of micro-perthitic structure, and does not give perfectly definite extinction.

Before leaving the Loch Dee mass, it is desirable that some reference should be made to the small subsidiary mass of Burnhead, which occurs about five miles S.S.W. of Carsphairn, and about $2\frac{1}{2}$ miles east of the main mass. It is more basic than the main mass, and illustrates the passage of quartz-augite-biotite-diorite into quartz-biotite-hyperite.

A specimen from the north-east margin of the mass, about 600 yards north-west of Burnhead (6679), is a dark grey massive rock containing a few felspar-phenocrysts. Under the microscope the rock is seen to be mainly composed of plagioclase, enstatite, augite, and biotite. There is also a small quantity of interstitial quartz, with which some alkali-felspar is probably associated. The plagioclase occurs as large more or less idiomorphic individuals, and crystalline groups, and also as small crystals, giving lath-shaped sections. The enstatite is but faintly pleochroic. It occurs both as grains and prisms, but the latter have

* Bull. des Services de la Carte Geol. de la France. No. 36 1893.

their angles rounded off. The augite is nearly colourless, non-pleochroic, and like the enstatite shows only slight traces of idiomorphism. Biotite is present in the form of very ragged plates. Iron-ores and apatite occur as accessories. When placed in a diffusion column the felspar of this rock is seen to lie between 2·68 and 2·71. A piece of labradorite floats in the middle of the space occupied by the felspar. It agrees, therefore, approximately with labradorite, but as the individuals are often zoned it is certainly not of uniform composition.

It is especially interesting to note that this specimen from the margin of the mass shows a marked tendency to a porphyritic structure.

A specimen from the centre of the mass, about 700 yards west of Burnhead (6681), is a medium-grained grey massive rock. It is composed of enstatite, augite, hornblende, plagioclase, alkali-felspar, and quartz. The plagioclase does not belong to two fairly well-marked periods of consolidation, as in the last specimen, and the quartz and alkali-felspar are well-developed, and were evidently the last minerals to consolidate. The occurrence of green hornblende shows that this rock is intermediate between the hyperites and the quartz-diorites.

Another exposure, from a point about 1000 yards south of west of Burnhead (6682), does not contain enstatite. Hornblende and biotite are the most abundant ferro-magnesian constituents, but augite, precisely similar to that of the hyperites, occurs frequently as cores in the hornblende. This rock is therefore a quartz-augite-biotite-diorite or augite-tonalite. Like the last, it contains interstitial quartz and alkali-felspar.

Rather less than half a mile south of the Burnhead mass, a very small boss of granite rock occurs on Mid Hill (6684). It is composed of plagioclase, enstatite, biotite, and hornblende, together with a small quantity of interstitial quartz and alkali-felspar, and is therefore intermediate between a quartz-augite-biotite-diorite and a quartz-biotite-hyperite.

We have now to consider the third large mass of granite occurring in the district of Galloway. The contact alteration produced by this mass has been the subject of communications by Mr. Allport and Dr. Bonney* and by Miss Gardiner,† but none of these communications gives a detailed description of the granite. Professor Bonney, in describing the specimens collected by Mr. Allport, remarks that "some are granophyres, more or less porphyritic; others true granites." One specimen contained wine-red garnets. The term granophyre in the above quotation is evidently not used in the sense in which that term is generally employed in this country and in Germany. Miss Gardiner gives an excellent description of the veins of aplite and

* "Report on the Effects of Contact Metamorphism exhibited by the Silurian Rocks near New Galloway." By S. Allport and T. G. Bonney. Proc. Royal Soc., London. Vol. xlix. (1889), p. 79.

† "Contact Alteration near New Galloway.' By Miss M. I. Gardiner. Quart. Jour. Geol. Soc. Vol. xlvi. (1890), p. 569.

pegmatite which traverse the highly altered rocks in the vicinity of Knocknairling Hill, but she does not describe the main mass of the granite itself. The only description, based on microscopic examination, which has hitherto been given, occurs in the Explanation of Sheet 5.* The two specimens there referred to come from the south-east corner of the mass. The one from the railway cutting near the viaduct over the Little Water of Fleet (1221) is a moderately coarse-grained grey granite composed of biotite, muscovite, one or two grains of hornblende, oligoclase, microcline, and quartz, together with apatite, zircon, and iron-ores as accessories. The oligoclase is white in this specimen, and the microcline pink, so that the two felspars are easily distinguishable; but this is evidently only a local peculiarity, for another specimen from the same locality (7024) does not show it. The other specimen from Sheet 5 was taken from Laughenghie Hill, about six miles north of Gatehouse of Fleet. It is a moderately coarse-grained biotite-granite, also containing interstitial microcline. Except that original muscovite is absent there is the closest possible resemblance in structure and composition between the rocks from these two localities. It was pointed out in the memoir already referred to that the specimens from that portion of the Cairnsmore of Fleet mass, which occurs within Sheet 5, were more acid than those from the main mass of Criffel. More extensive observations prove that the Cairnsmore of Fleet mass as a whole is more acid than either of the two other masses. Specimens from Bennan Hill (7025), on the west side of Loch Ken, anl also from the wood near Lochside (7030), on the west side of Loch Ken, from Knocknairling Hill (7027), near New Galloway, from a point south of Craigdews (7029), about five miles south by east of Loch Dee, and from Clatteringshaws (7031), six miles west of New Galloway, all bear a very close resemblance to the two rocks above referred to. They are medium or coarse-grained light grey granites, which occasionally show a gneissose structure. A slight tendency to a porphyritic or rather pseudo-porphyritic structure may sometimes be noticed. The felspars which give rise to this porphyritic aspect do not, as in typical porphyritic rocks, belong to the earlier phases of consolidation. Their cleavages are interrupted by inclusions of oligoclase, quartz, and biotite, and they can be found by microscopic examination to be, at any-rate in most cases, microcline or microcline-microperthite. Their cleavage surfaces often show a pearly lustre. When the fractured surface of a specimen of the normal granite from this mass is examined with a lens quartz may be readily detected in great abundance, and the grains not unfrequently show a rude tendency to idiomorphism at the expense of the felspar. The rocks are in most cases massive, but occasionally, as at Clatteringshaws Bridge, a distinctive foliation may be observed.

The principal constituents of this granite mass are oligoclase,

* Memoirs of the Geological Survey of Scotland. 1896.

biotite, alkali-felspar, and quartz. Muscovite is occasionally present, and the rock then becomes a typical muscovite-biotite-granite. Hornblende has been observed only in one or two cases. Rocks of the tonalite type, which are so common both in the Criffel and Loch Dee masses, have not been observed in the Cairnsmore of Fleet mass. Apatite, zircon, iron-ores, and in one case (7030) monazite, occur as accessories.

The mutual relations of the principal constituents are essentially the same as in the other granite masses. Oligoclase and biotite belong to the earlier, quartz and alkali-felspar to the later phases of consolidation. There is, however, a marked difference in the relative proportions of the different constituents. The average proportion of the quartz and alkali-felspar to the oligoclase and biotite is much greater in this mass than in the other two masses, although portions of the Loch Dee mass are practically identical with the dominant rock from the mass now under consideration.

As regards the individual constituents, the oligoclase and biotite do not call for special description. The latter mineral is occasionally replaced by chlorite and epidote, and the former is often rendered turbid by the development of small scales of a micaceous mineral. In those rocks which contain original muscovite this mineral is developed either in independent plates or is found associated with the biotite. The alkali-felspar is either moiré-orthoclase or microcline, generally the latter. It is abundant, and often occurs in large more or less irregular individuals, which are sometimes twinned on the Carlsbad plan. The fact that these large individuals give a kind of porphyritic aspect to the rock as a whole has already been referred to. They contain biotite, oligoclase, and sometimes quartz as inclusions. Quartz is abundant. It occurs as irregular grains, often of considerable size, and two or more grains usually occur in juxtaposition. In describing the hornblende-granitites and tonalites reference has been made to the fact that the quartz of these rocks often possesses an ophitic character; portions wedged in between the other constituents frequently give uniform extinction in the same way as the augite of ophitic dolerites. In the rocks now under consideration this feature is not noticeable, although the quartz is certainly on the whole of later date than the oligoclase and biotite. In the gneissose varieties of rock the polysynthetic character of the quartz is more marked than in the massive varieties, and the individuals composing the aggregates are often elongated in the direction of the foliation, as if the interstitial movement which accompanied the development of the parallel structure had affected the quartz more than any of the other constituents. The junctions of contiguous individuals in these polysynthetic aggregates are very irregular, and of the kind for which Professor Blake has proposed the term "sutural," because they are somewhat similar to the sutures of the skull.

In the Annual Report of the work of the Survey for 1895, a preliminary account of the older Cairnshee granite of Deeside

has been published, and special attention has been called to the alkali-felspar, as it is developed in that rock. Almost all that has been there said will apply equally to the alkali-felspar of the Cairnsmore of Fleet mass. In both rocks we find the same relation between moiré-orthoclase and microcline, the same tendency to pseudo-porphyritic structure, and the same relation to the other constituents.

The accessory minerals, apatite, zircon, and iron-ores, do not call for special description, but the monazite deserves more than a passing notice. Unfortunately only one crystal has been observed in the thin section. It occurs in a specimen collected near Lochside, on the west side of Loch Ken (7030). It is honey-yellow in colour, and shows faint pleochroism, together with very high refraction and double-refraction. Traces of crystalline faces may be seen, but they cannot be identified. The crystal measures only one mm. across. That it is monazite is proved not only by the characters above referred to, but also by the presence of the more important of the two didymium absorption bands in the spectrum of the light which has passed through the crystal. The rocks from the main mass exhibit only slight variations in composition. They are all true granites, with a considerable amount of quartz and microcline. Most of them are biotite-granites or granitites, but true muscovite-biotite-granites also occur. This latter point is interesting, because, as a rule, the biotite-granites and granites with two micas do not occur together as parts of the same mass.

The most marked deviations from the dominant type are to be found in the contact zone. These have been described by Miss Gardiner as aplite veins in the paper already cited. She says, "The rock is usually very coarse, but here and there becomes fine-grained. It consists of felspar (often in large masses), quartz, and a considerable quantity of white mica. Tourmaline and granet are accessory minerals. "The felspar is mostly microcline. In some veins it forms a micro-pegmatite with quartz, in others it forms the bulk of the rock. In one vein, to the west of the granite, there are masses of it two or three feet across, with continuous cleavage planes some inches long. The felspar often includes garnets. The quartz is traversed by many lines of small inclusions. That associated with the large felspar masses just mentioned can be seen with a hand lens to consist of small, flattened, hexagonal prisms, with pyramids at one end built up in parallel zones. The white mica is often in hexagonal plates, as much as half an inch in diameter. Along the edge of one of the veins on Knocknairling Hill there are triangular flakes arranged in a plumose manner. The mica feathers point inwards from the edge of the dyke, and are three to four inches long.

"The small garnets are sometimes of a brownish red, as in the altered grits, and sometimes of a bright wine-red colour. Large yellow garnets occur occasionally.

"Tourmaline occurs in the Knocknairling Hill vein in patches

curiously intergrown with quartz, so as to form what looks like a graphic granite, with the little hooked letters in dark tourmaline instead of quartz. The tourmaline needles are parallel with each other instead of radiating as in luxullianite. Some of it is an indigo, and some a bottle-glass brownish-green colour. These tourmaline-quartz patches have an area of one or two square inches. Groups of tourmaline sections extinguish together, but the quartz grains have their axes at all angles.

"The fine-grained variety of aplite has a sparkling saccharoidal look, and the little pink garnets show conspicuously on the white surface of a freshly broken specimen. It consists of about equal quantities of felspar and quartz in grains. There is a good deal of white mica; garnets are common, and small needles of tourmaline occur occasionally. In some places coarser veins shade off in parts into this fine-grained material, and in others it occurs in veins by itself."

These veins of aplite and pegmatite occur in a zone of intense metamorphism. They are essentially composed of that portion of the granite magma which consolidated last in the main body of the rock. Mr. Barrow has called attention to the tendency of the mother liquor of granitic magmas in the Central Highlands to penetrate the surrounding rocks, and to form pegmatite veins which often contain white mica. Similar phenomena may be seen in Cornwall, as, for example, at Trewavas Head, where there is the same association of fine-grained aplite and coarse-grained pegmatite with tourmaline as at Knocknairling Hill. The phenomena in question occur on a much smaller scale in the Galloway district than they do either in Cornwall or in the Southern Highlands. They are specially developed on a large scale in association with muscovite-biotite-granites, and, as we have already noticed, these rocks are rare in the Cairnsmore of Fleet mass.

We may now summarise the principal results obtained from this petrographical study of the Galloway granites. The Criffel mass, taken as a whole, appears to be the most basic. Plagioclase felspar predominates, and a large portion of the mass is a tonalite rather than a true granite. Dark basic inclusions of a dioritic rock are common, and acid veins essentially composed of quartz and orthoclase also occur. Clove-brown crystals of sphene are scattered through the mass, and it is rare to find a hand specimen in which one or more crystals of this mineral may not be detected with a lens. Hornblende, biotite, and oligoclase are the dominant minerals, and belong to the earlier phases of consolidation. Quartz and orthoclase play the rôle of ground mass. Augite is present as cores in the hornblende, thus giving rise to augite-granitites and quartz-augite-biotite-diorites.

The Loch Dee mass presents in many respects a close resemblance to the Criffel mass, and large portions of it are composed of hornblende-granitite and granitite. Augite is occasionally found, and by its local increase, coupled with a corresponding diminution in the amount of hornblende, the augite-granites

pass into quartz-augite-biotite-diorites. By a further modification in the same direction, along with the coming in of enstatite and a decrease in the quartz and felspar, the quartz-augite-biotite-diorites merge into quartz-biotite-hyperites. Certain other portions of the same mass illustrate a change in the opposite direction. The ferro-magnesian constituents and oligoclase decrease in amount, and the quartz and alkali-felspar increase. Moreover, the alkali-felspar may be developed as microcline, and may take on the form of pseudo-porphyritic crystals with inclusions of biotite, quartz, and oligoclase. Rocks of this latter type have not been observed in the Criffel mass, though it is perhaps scarcely safe to assert that they do not occur. The most acid rocks of the Loch Dee mass occur as apophyses of aplite and pegmatite in the contact zone. The mass of Burnhead, which is subsidiary to that of Loch Dee, is more basic than the main mass, and consists of quartz-biotite-hyperite and quartz-augite-biotite-diorite.

Biotite-granite or granitite with microcline, which is locally developed in the Loch Dee mass, forms the dominant rock of the third or Cairnsmore of Fleet mass. Hornblende, which is often present in the Loch Dee mass, and extremely common in the Criffel mass, is only locally present in the Cairnsmore of Fleet mass, and may, in all the specimens examined, be regarded as an unimportant and accessory constituent. A point of great interest in connection with this mass is the evidence it affords of the relation between granites with one mica only and those with two micas. The biotite-granites with microcline are here definitely associated with typical muscovite-biotite granites. Beyond the presence of muscovite there is no difference either in structure or composition betwen the two types of rock. Veins of aplite and pegmatite occur as apophyses, and contain muscovite, tourmaline, and garnet. The white-mica-bearing pegmatites are especially characteristic of a zone of intense metamorphism in the surrounding rocks.

It appears, therefore, from the preceding account that the three great masses, which must all be approximately of the same geological age, present certain points both of resemblance and difference. The Criffel mass appears to be the most basic, and the Cairnsmore of Fleet mass the most acid, whilst the Loch Dee mass occupies an intermediate position. This remark, however, can only be regarded as true in a broad and general sense when reference is made to the average composition of each of the three masses. In each we find rocks which are more basic and more acid than the general average. It is probable that the aplite veins of the Criffel mass do not differ markedly in composition from the corresponding rocks of the Cairnsmore of Fleet mass. They should, indeed, be substantially identical if in each case they represent the mother liquor of the granite magma, for this is proved by microscopic examination to have yielded quartz and alkali-felspar in all the rocks.

The different varieties of rock occurring in each mass, and in

the three masses regarded as a whole, are closely bound together by transitional forms. If we leave out of account the veins of aplite and pegmatite, then the most basic rocks are represented by the diorites of the Criffel mass and the hyperites of the Loch Dee mass. The most acid rocks are represented by the muscovite-biotite-granites of the Cairnsmore of Fleet mass. Between these extreme types we have a continuous series of intermediate varieties.

In concluding this account of the Galloway granites it seems justifiable to offer some remarks on the bearing of the facts on the more or less rival theories of assimilation and differentiation. If one or other of these theories must be accepted to account for the facts above described, the preference must undoubtedly be given to the latter. Neither the local differences observed in one and the same mass, nor the general differences which become noticeable when the three masses are compared with each other, can be correlated with the nature of the rocks into which the granite has been injected. Moreover, the junctions of the granite with the surrounding rocks are in general perfectly sharp, and furnish no support to the view that the granite either represents the sediment crystallised in place or has even had its composition appreciably modified by the assimilation of portions of the surrounding rock. On the other hand, the aplite veins, corresponding as they do in composition with those portions of the granite magma which consolidated last, seem to furnish direct evidence that some at least of the differences which we observe are to be accounted for by the differentiation hypothesis. In the absence, however, of any well-established physical laws which will satisfactorily account for the differentiation, the hypothesis cannot be said to rest on an assured basis. There can, however, be no doubt that even in its present unsatisfactory state it has an enormous advantage over its rival, so far as the phenomena of the Galloway granites are concerned. On this hypothesis the differences in the average composition of the three great masses would be explained by differentiation in a deep-seated reservoir or magma basin; whereas the differences observed in one and the same mass might be explained partly by the intrusion of a heterogeneous magma and partly by differentiation after the magma had reached its present position. In addition to the three large masses of plutonic rocks above referred to there are several smaller masses, which will now be briefly described.

In the extreme west a small granite mass occurs a few miles north-west of the Mull of Galloway (Sheet 1). This is represented in the Survey Collection by four specimens. One from Crummag Head is a grey hornblende-granitite with sphene; another form Portencorkrie Bay is a pinkish rock containing the same minerals, but having a larger amount of alkali-felspar, which is sometimes developed as micro-perthite; a third from Lagantalluch Head is an augite-biotite-diorite containing a small quantity of enstatite, and therefore having affinities with

the hyperites; the fourth from a point 300 yards north of Portencorkrie is similar to the last in composition, but contains a larger amount of biotite, which is conspicuous in the hand specimen, and gives the rock the appearance of a kersantite.

Several small granitic masses occur in Sheet 4. That south of Glenluce, coloured on the map as diorite, contains quartz-diorite (tonalite), augite-diorite with micro-poikilitic brown hornblende, and an augite-diorite with enstatite, and is therefore allied to the hyperites.

The mass about three miles north of Kirkcowan, also coloured diorite, is composed of similar rocks. On the east side of the estuary of the Cree, south of Creetown, is an important granite quarry. The principal rock in this quarry is a moderately coarse-grained grey granitite, the felspars of which contain a considerable amount of secondary white mica.* On the south side of the quarry there is also a fine-grained grey rock of somewhat earlier date than the normal granite. It is composed of small phenocrysts of zonal plagioclase and aggregates of biotite and epidote in a micro-crystalline ground mass, also containing small patches of biotite and grains of epidote.

Some interesting gneissose rocks, formed by injection and superposition, occur at the south junction in this quarry. The pure sediment is represented by a brown biotite-hornfels, traversed by narrow green bands and lenticles composed of hornblende, epidote, grossularia, sphene, quartz, calcite, and perhaps malacolite. The garnet, which gives a brown colour to the bands, and is normally present only in the central portions, is of the type common in altered limestones, and often shows double refraction. The original rock was probably a sandy shale containing impure calcareous layers.

The mixed rock (248) is composed of broad bands of biotite-hornfels containing prisms of green hornblende and thin folia of a syenitic rock formed of green hornblende similar to that occurring as pseudo-porphyritic crystals in the biotite-hornfels, alkali-felspars, quartz, and sphene. The specimen on which this description is based resembles a gneiss in appearance, and is bounded on one surface by a band of calc-silicate hornfels containing brown garnet.

The small mass of the Cairnsmore of Carsphairn which occurs on the north-east corner of Sheet 8, and enters also into the adjacent Sheets, has yielded specimens of granitite, hornblende-granitite with sphene, quartz-augite-biotite-diorite, and quartz-biotite-hyperite.

Some altered rocks from this mass contains pyrrhotite. In view of the fact that the pyrrhotite associated with norites and hyperites often contains from three to five per cent. of nickel, a small quantity of this mineral was isolated from one of the rocks and tested for that metal. Only somewhat doubtful traces were

* Since this was written, Mr. J. S. Flett has described (Geol. Mag., 1898, p. 388) orthite from this rock which he regards as a true granite with muscovite and epidote as original constituents

found. Although the amount of pyrrhotite employed was small, it was quite sufficient to prove that nickel is not present in anything like the same quantity as it is in the mineral which is used as an ore in Sweden and in the Sudbury district of Canada.

All the localities above referred to lie within the ancient district of Galloway. There are, however, one or two small granitic masses situated outside this district in Sheet 15, near New Cumnock. The Polshill mass is formed of hornblende-granitite or tonalite, with a margin, at any rate at one point, where the Polshill Burn crosses the junction, of quartz-biotite-hyperite. The granite of Spango Water is represented by one specimen (6543), which is a granitite of the true Galloway type.

It thus appears that the plutonic rocks which lie between Spango Water and the Mull of Galloway, and between Loch Doon and the Solway Firth, are all intimately related. The same types reappear in widely separated localities, and there can be no doubt that they all belong to the same petrographical province.

The Survey collection contains several specimens from the small mass of granite at Priestlaw on the Southern slopes of the Lammermuir Hills, of which, three have been sliced. The first (No. 7808) from the Faseny Water, Priestlaw, is a hornblende-biotite-granite; the second (No. 7809) from the same stream, near the edge of the mass, is a more basic rock than the preceding one, with porphyritic, zoned plagioclase in a micrographitic aggregate of biotite, hornblende, felspar and quartz. It might almost be termed a hornblende-biotite-porphyrite, but the ground-mass is somewhat coarser in grain—more granitic—than in the typical porphyrites. The specimen is interesting as showing that the physical conditions, under which the marginal portions of the Priestlaw mass consolidated, approximated to those under which the porphyrite dykes were formed. The third specimen (No. 7810) also from the edge of the mass in the Faseny Water is a quartz-augite-biotite-diorite. This rock differs from the quartz-biotite-hyperites, only in not containing hypersthene. The pale-green augite (malacolite), which occurs to the almost entire exclusion of hornblende, and the general structure of the rock, are precisely similar to the corresponding features in the hyperites.

DYKES.

Dykes are extremely abundant in the Galloway district, and especially so in the neighbourhood of the Criffel and Loch Dee masses. Those which occur in Sheet 5 have already been described in the Memoir on that sheet, and the main facts are here reproduced.

1. *Porphyrites.*

The dykes occur not only in the sedimentary rocks but also in the granitic masses, and the same petrological types are found in

both areas. The vast majority is formed of rocks to which the term porphyrite has been applied. This term has hitherto been employed in a different sense in the publications of the Geological Survey, and a word or two of explanation is therefore necessary. Recent research has established the fact that the so-called porphyrites which occur as lavas in association with Palæozoic sediments are merely altered andesites. The continued use of the term in its old sense is therefore undesirable, and will accordingly be dropped. The word may, however, be conveniently employed in accordance with the usage adopted by American petrographers (Prof. J. P. Iddings, "The Eruptive Rocks of Electric Peak and Sepulchre Mountain," *Twelfth Annual Report of the U.S. Geological Survey*, 1890-1891) for rocks of the type now under consideration, Such rocks occur for the most part as dykes, sills, and laccolites. They bear the same relation to the andesites that the porphyries do to the liparites.

These rocks are, as a rule, markedly porphyritic in structure. Plagioclase, hornblende, and biotite commonly occur as phenocrysts; quartz is occasionally found; orthoclase is very rare. The ground-mass is usually compact. The rocks vary in colour from grey to red; the latter tint being characteristic of the most highly altered varieties. The proportion of phenocrysts to ground-mass is liable to considerable variation, some rocks containing so little ground-mass as to resemble granites; others containing so few phenocrysts as to have the character of felsites. These extreme types are, however, comparatively rare.

In the typical rocks of the group, plagioclase is always the most conspicuous phenocryst, both on account of its abundance and of the size of the individuals. It occurs in single crystals, in crystalline groups, and as crystal fragments. Twinning on the Carlsbad-, pericline- and albite-plan may often be observed. The individuals are often beautifully zoned, and by employing the Becke-effect it can frequently be demonstrated that narrow zones of a highly refractive and therefore basic felspar, are repeated several times in a single individual. The plagioclase is liable to the micaceous type of decomposition, and many rocks are so highly altered that the optical characters of the mineral can no longer be observed.

Orthoclase phenocrysts have not been identified with certainty in any of the microscopic sections, but one or two large, irregular grains, measuring half-an-inch or more across, were observed in a dyke from the south-east spur of Criffel.

The phenocrysts of hornblende and biotite are not so large as those of plagioclase. The hornblende is usually of the green type common in the granites and quartz-diorites, but a brown variety has been observed in one or two instances. As compared with the hornblende of the granite, it is remarkable for the perfection of its crystalline form. The faces of the prism and of the two vertical pinacoids are often present. Twinning of the common type may frequently be observed. The biotite is also

remarkable for the perfection of its crystalline form. It occurs in hexagonal tablets, but in other respects resembles the biotite of the granites and quartz-diorites.

Quartz, when present as a phenocryst, possesses the same characters as the quartz of the porphyries. It occasionally shows an approach to the dihexahedral form, but as a rule occurs only as corroded grains. It contains inclusions with bubbles.

The ground-mass varies in different rocks. In some cases the minerals which occur as phenocrysts—plagioclase, hornblende, and biotite—may all be recognised together with quartz and alkali-felspar; in others the constituents of the ground-mass cannot be definitely determined, on account of the small size of the individuals and the confused nature of the crystallisation. Micro-poikilitic, micro-pegmatitic, and in one case, spherulitic structures have been observed. It is highly probable that quartz and alkali-felspar enter largely into the composition of this part of the rock.

It follows, from the above description, that there is very little difference in composition between the dykes of this type and the granitic rocks of the Criffel and Dalbeattie mass. This is confirmed by the following table of specific gravities:—

One mile N.N.E. of Red Bank Farm (6584), dyke in granite,	2·65
Three-quarters of a mile E.S.E. of the top of Screel, - -	2·657
One mile north of Dalbeattie (1262), - - - - -	2·67
Near the summit of Ben Gairn (6578), - - - - -	2·67
North of Croft-Head; six miles north of Dalbeattie (1233) -	2·65

It is probable, therefore, that the structural differences between the porphyrites and the hornblende-granites or quartz-diorites are due to differences in the conditions under which the magmas consolidated. If we suppose that an intrusion of the granitic magma took place in dyke form after the greater part of the hornblende, biotite, and plagioclase had separated out, we shall have a satisfactory explanation of the difference in structure between the porphyrites and the granitic rock. In applying this theory, however, it must be remembered that dykes of the type now under consideration occur not only in the sedimentary rocks but also in the granitic masses. Moreover, dykes are found in the foliated area unaffected by the foliation. Such dykes cannot be regarded as in any way representing apophyses of the granite. They belong to a later phase of igneous activity. The source of supply was probably the same as that from which the main igneous mass was derived; but if so, it must have been tapped at a time when crystal building had proceeded to a considerable extent.

One fact tells somewhat against the view suggested above, and that is the not infrequent occurrence of quartz and the occasional presence of orthoclase amongst the phrenocrysts of the porphyrites. In the granitic masses these minerals invariably belong to the final stage of consolidation. The difficulty, however, may not be serious, for the quartz is almost always intensely corroded, and both minerals have rather the aspect of foreign constituents.

2. *Diorites.*

The typical representatives of this group are medium or fine-grained dark-coloured crystalline rocks essentially composed of hornblende and a plagioclase felspar. In some specimens the hornblende may be clearly recognised with a lens in the form of long slender prisms. These rocks are denser than the porphyrites, the specific gravity ranging from 2·68 to 2·81. The hornblende is often seen to be of a deep brown colour under the microscope. It may be either idiomorphic or ophitic with respect to lath-shaped plagioclase. The idiomorphic hornblende is occasionally zoned (1269). Green hornblende is also present, and this may arise from the alteration of the brown variety, or, as seems probable in some cases, from the alteration of an original pyroxene. Twinning is not infrequent.

The felspar, which is generally turbid, may occur in forms giving lath-shaped sections or as irregular grains which fit together so as to form the matrix in which the hornblende is embedded. Sometimes there is a little interstitial quartz, but this mineral never forms any large portion of the rock. Biotite is sometimes present. Apatite is often abundant in the form of slender prisms; iron ores are scarce or altogether absent. Chlorite, epidote, and sometimes carbonates, occur as alteration products.

Those rocks in which the hornblende is present in the form of slender prisms, belong to the camptonite division of the lamprophyres (see Plate XXV., Fig. 2).

3. *Mica-Traps.*

The specimen from Greenhill, east of Meiklewood, is a dark-coloured rock, composed of numerous tablets of brown mica, embedded in a compact matrix. Under the microscope the mica is seen to possess the usual characteristics of that mineral as it occurs in mica-traps. The tablets are thin in proportion to their breadth; their margins are often more deeply coloured than the central parts; and the absorption for rays vibrating at right angles to the vertical axis is far less marked than it is in the biotite which occurs in the granites. The mineral is biaxial, with a very small optic axial angle. Biotite is the only phenocryst which has preserved its original characters, but there are pseudomorphs in quartz or quartz and carbonates after some other mineral—possibly augite. The groundmass of the rock is composed of small scales of biotite, felspar, carbonates, magnetite, and apatite. The felspar forms the matrix in which the other constituents are embedded. It does not show multiple twinning, and, as the refractive index is lower than that of the balsam in which the section is mounted, it is probably orthoclase. Magnetite occurs in small crystals and grains which are uniformly scattered through the section. The carbonates, as is so frequently the case in comparatively unaltered rocks of this

type, cannot be attributed to the decomposition of any one mineral.

The specimen from Nun Mill is purplish in colour, and much more altered than the one above described. It is composed of biotite, pseudomorphs in carbonate after phenocrysts of augite (?), magnetite, and felspar. The felspar is altered and stained with ferric oxide, so that its precise character cannot be determined.

Both rocks are probably minettes.

The dykes from other portions of the Galloway district agree in general characters with those from Sheet 5. They comprise porphyrites, diorites of the camptonite type, mica-traps, and hyperites. By far the most abundant rock is a porphyrite. The rocks belonging to this type vary in colour, texture, and composition, but the distinctive characters, which are the presence of porphyritic crystals of plagioclase, and one or both of the ferro-magnesian constituents, biotite, and hornblende, in a compact matrix, may generally be recognised. In colour the rocks vary from pale grey to almost black; pink varieties also occur. The felspars are as a rule not conspicuous, one-eighth of an inch being a common size. The rocks are not unfrequently much altered, and the ferro-magnesian constituents are often entirely replaced by chlorite, epidote, and carbonates. The principal differences in composition depend on the presence or absence of quartz or hornblende. Thus arise varieties to which such terms as quartz-hornblende-biotite-porphyrite, quartz-biotite-porphyrite, hornblende-biotite-porphyrite, and biotite-porphyrite may be applied. But these differences are not strongly marked. Quartz-porphyrites are comparatively rare.

All the specimens available have been carefully examined with a view to determine whether true quartz-porphyries occur. In describing the dykes from Sheet 5, attention has been called to the occurrence in one or two of a few large crystals of orthoclase. These are, however, so rare and exceptional that it is doubtful whether they should be separated from the porphyrites, especially as plagioclase, even in these rocks, is the dominant porphyritic felspar. In some other cases the felspars are so much altered as to be indeterminable, but there is no reason to regard these rocks as other than altered forms of porphyrite. We may say that true quartz-porphyries have not been recognised. If they do occur they will probably be found in association with the Cairnsmore of Fleet mass.

A glance at the map (Sheet 8) shows that a vast number of porphyrite dykes occur in the immediate neighbourhood of the Loch Dee mass. These appear to be on the whole somewhat more acid than the corresponding rocks associated with the Criffel mass. The phenocrysts, and especially those of biotite and hornblende, are not so conspicuous. A very common type is a pale grey porphyrite, in which the porphyritic structure is not very marked in the hand specimen, although it is at once evident under the microscope. As a rule, the felspar is turbid, and the ferro-magnesian minerals, which are by no means abundant,

have been largely replaced by chlorite and carbonates. Examples of this type occur on the top of Craigrine Hill (2531), five miles S.S.W. of Carsphairn; on the top of Meikle Craigrarson, 6¼ miles south-west of Carsphairn; at Cullendoch, 5 miles N.W. of Cairsphairn; at Garryhorn Gairy, three miles west of Carsphairn; on the top of Gairy Craig, 1¼ miles south of Carsphairn (707); east of Meadowhead, 4¼ miles N.N.W. of Carsphairn; south and west of Meaul Hill, 4¼ miles south-west of Carsphairn; and on the Coran of Portmark, four miles west of Carsphairn.

Intimately connected with the above are some dark-coloured biotite-porphyrites containing glassy plagioclase. Examples of these occur on the top of Meikle Craigrarson (2557), and near the head of Downies Burn, five miles north by east of Loch Dee (2555). A specimen from the west side of Meaul Hill (7022), which is somewhat intermediate between the two types, so far as general appearance is concerned, may be described in detail. The rock is dark grey or bluish grey in colour. Phenocrysts of felspar, and of a dark ferro-magnesian mineral, may easily be recognised with a lens when the surface is wet. The groundmass is compact. Under the microscope the phenocrysts of plagioclase are seen to occur in crystals, crystalline groups, and as crystal fragments. They are often beautifully zoned, but in all cases examined they possessed a higher refractive index than balsam, and possibly range in composition from labradorite to andesine or basic oligoclase. Twinning is present, but is not a conspicuous feature. The ferro-magnesian minerals are represented by biotite and by pseudomorphs in carbonate after hornblende. The ground mass is a confusedly crystalline aggregate of quartz and felspars, with which small scales of biotite are associated. Much of the felspar of the ground mass is doubtless orthoclase.

Pink porphyrites occur in the Water of Deugh, two miles north of Carsphairn, south of Thorny Hill, 3¾ miles south of Carsphairn Gairy, south-west of Craigrine Hill (707), five miles S.S.W. of Carsphairn, in the Lorg Burn (head of Ken), in Polvaddoch Burn (head of Ken Water), and at the head of Barend Burn, south-east of Balmaclellan.

Dykes other than porphyrites are rare. They are represented in the collection by a few specimens. A diorite of the camptonite type occurs at Lorg Hill, Cordorkan Burn, four miles south-west of Loch Dee (724 and 2538). In the hand specimen it appears as a dark grey, medium-grained rock, composed of idiomorphic hornblende in a white felspathic matrix. Under the microscope the hornblende is seen to be of a deep brown colour. The dominant felspar is more or less idiomorphic, and there is some orthoclase and quartz. A little augite was probably present in the original rock, but if so it has been replaced by pale greenish chloritic decomposition products.

A rock in some respects intermediate between a hornblende-porphyrite and camptonite occurs on Black Gairy Hill, five miles

south-west of Loch Dee. It consists of phenocrysts of brown hornblende in a fine-grained ground mass similar to that of many porphyrites. This rock differs from the ordinary porphyrites in the absence of porphyritic felspars. A mica-trap occurs in Kirreoch Burn (1612). It consists of ragged plates of biotite and pseudomorphs in carbonate after augite (?). The matrix is felspathic, and the felspars show a tendency to a feathery mode of aggregation. The rock is too much altered for precise determination, but it was probably a minette. There are also other dykes which are intermediate between typical biotite-porphyrites and kersantites. A dyke of hyperite occurs at Braidenoch, two miles south of Carsphairn (698). It is a quartz-biotite-hyperite, precisely similar to the rocks associated with the Loch Dee mass, and is of special interest as proving that the hyperite-magma was not only formed in connection with the main granitic masses, but was also intruded in the form of dykes.

In many regions where dykes occur in association with plutonic rocks they belong to two fairly well marked groups, the one group being more acid, and the other more basic than the plutonic mass. Professor Brögger has proposed that the two groups taken together should be referred to as complementary dykes. The facts described above prove that in the Galloway district the dykes are not sharply divisible into two groups. It is probable that if we had a sufficient number of analyses of the granites and diorites which make up the masses of Loch Dee and Criffel, and also of the dykes which occur in association with these masses, that the two sets of analyses would closely correspond. Both sets would show variations, but these variations would be similar, and the relative proportions of the different types would be similar. The main difference between the dykes and the granite masses is a structural one, depending on the fact that in the dykes two periods of consolidation are sharply defined, whereas in the granitic mass they merge gradually into each other.

It is somewhat remarkable that true quartz-porphyries have not been detected in the Galloway district. This is doubtless due to the fact that the dominant type of rock in the Loch Dee and Criffel masses is a basic granite or tonalite. Plagioclase is as a rule the dominant felspar. The Cairnsmore of Fleet mass is more acid, but the dykes in its neighbourhood do not appear to be so numerous as they are in the vicinity of the other masses. It is probable that if the more acid portion of the magma which consolidated as the Cairnsmore of Fleet mass had been intruded in the form of dykes, it would have given rise to quartz-porphyries similar to those which occur so abundantly in the West of England in association with the muscovite-biotite-granites of Devon and Cornwall.

CHAPTER XXVII.

CONTACT-METAMORPHISM AROUND THE GALLOWAY GRANITES.

THE granites of the Galloway district have produced important alterations in the sediments into which they have been intruded. In his remarkable paper on "The Convolutions of Strata and their Meeting with Granite," Sir James Hall* calls attention to these alterations. In speaking of the exposures on the west side of Loch Ken, where he traced the granite veins to their junction with the main mass, he says: "In the immediate neighbourhood of the granite, to the distance of a foot or two, and not more, the stratified matter has in many instances assumed a highly micaceous character so as to deserve the name of mica-slate, and perhaps gneiss." And again: "The quality of this stratified mass [the Silurian formations of the Southern Uplands of Scotland] from one side of the island to the other seems to be uniform throughout, except in the immediate neighbourhood or contact of the granite, where it assumes a micaceous character, approaching to the character of gneiss or mica-slate. This furnishes a most notable indication of the action of heat, since the granite, by its local intensity, has performed the very effect which Dr. Hutton ascribes to the general heat below, as acting upon the lower beds, and converting them into gneiss."

These two quotations prove that Sir James Hall not only recognised the metamorphic effect of the granite upon the adjacent sediments, but that he realised the importance of the facts in relation to the origin of extensive areas of gneiss and schist. The concluding sentence of the second quotation contains the germ of the theory, recently advocated by M. Michel Lévy in France, that the extent of the contact zone is dependent on the depth at which the intrusion took place. The exposures of granite are regarded in many cases as the apices of pyramids, which expand downwards, and regions of gneiss and schist are supposed to represent areas where denudation has been carried on to such an extent as to expose the lower portions of the "appareils granitiques." It will be shown in the sequel that the metamorphism of the sediments extends to much greater distance than was recognised by Sir James Hall.

A long time elapsed after the memorable observations by Sir James Hall before the phenomena of contact-metamorphism in the Galloway district again attracted the attention of geologists.

* Trans. Roy. Soc. Edin. Vol. vii., p. 79.

During the progress of the Geological Survey they were found to occur on a large scale round each of the three important masses, and an extensive series of specimens was collected. A general account of the metamorphism was given in the Memoirs explanatory of Sheets 9 (1877) and 4 (1878), and special attention was called to the crystallisation of the sediments and to the development of mica in the neighbourhood of the granites.

In recent years the two important communications already cited, have been published, containing descriptions of the microscopic characters of the metamorphic rocks, the one by Messrs. Allport and Bonney,* and the other by Miss Gardiner.† Both papers relate to the alteration surrounding the Cairnsmore of Fleet mass.

Messrs. Allport and Bonney especially describe the change which has been effected in sediments, varying from "silky clays to greywackes," along the west side of Loch Ken. They record the presence of quartz, brown mica, white mica, hornblende, augite, garnet (rare), epidote (not common), tourmaline (rare), and black opaque materials. They conclude that the biotite which is so extensively developed in argillaceous sediments must be an iron-mica, containing only a small percentage of magnesia.

In describing the alteration of the greywackes, they call attention to the partial destruction of the typical clastic structures. Only the ghost of such structures remains in the altered rocks. The original quartz grains are represented in the altered rocks by subangular individuals, which are larger than the constituents of the quartz-mica aggregates, and the original felspars have been replaced by chalcedonic or micro-crystalline quartz containing minute flakelets of white mica.

Miss Gardiner's paper deals especially with the altered rocks occurring in Knocknairling Burn and in the neighbourhood of Knocknairling Hill, to the west of the town of New Galloway. The progressive changes seen in beds of grit and shale as they are traced along the strike towards the granite are described. The grit is shown to pass into a coarsely crystalline gneissose rock, composed of quartz, two micas, garnet, and sillimanite, and to contain in the immediate neighbourhood of the granite lenticles of quartz and garnet. The garnet-sillimanite-mica-quartz rocks described and figured by Miss Gardiner must certainly be regarded as some of the most remarkable products of contact-metamorphism hitherto described. In the same paper it is proved that the shales are converted into schistose aggregates of quartz and two micas, with which opaque dusty matter and occasionally large crystals of chiastolite are associated.

We now proceed to give a general account of the metamorphism of the Galloway district, based on specimens in the Survey

* "Report on the Effects of Contact-Metamorphism exhibited by the Silurian Rocks near the Town of New Galloway." Proc. Roy. Soc. London. Vol. xlix. (1889), p. 79.

† "Contact Alteration near New Galloway." Quart. Jour. Geol, Soc. Vol. xlvi. (1890), p. 569.

Collection. Most of these specimens have been collected from the contact zone surrounding the Loch Dee mass, but the specimens from other areas are sufficient to show that the different masses do not present any marked differences as regards the nature of the products formed. Where similar rocks have been acted upon to the same extent the resulting products are the same.

The rocks which have been metamorphosed comprise grits, greywackes, ordinary shales and slates, black shales highly charged with carbonaceous matter and pyrite, radiolarian chert, impure calcareous rocks, and the igneous rocks underlying the radiolarian cherts. A special feature of the Silurian rocks of the Southern Uplands is the great development of both coarse and fine-grained grits and greywackes of complex composition. Normal argillaceous sediments make up only a small portion of the area. It follows, as a necessary consequence of this fact, that the contact phenomena surrounding the Galloway granites must differ in a marked manner from those observed in the Skiddaw district, and in that portion of the Vosges which has been rendered classic by the remarkable memoir by Professor Rosenbusch.*

When a granite mass is intruded into sediments of uniform composition, as in the case described by Professor Rosenbusch, the metamorphic zone may be separated into subordinate zones characterised by special minerals or by special structures. The successive zones represent different grades of metamorphism in one and the same type of rock, and they are concentric with reference to the granitic mass. When, however, as in the case of the Galloway granites, the intrusion has taken place in a set of complex sediments of variable character, the separation of the metamorphic aureole into subordinate zones, continuous round the central mass, becomes impossible. Each member of the complex group possesses its own special type of metamorphism, and a sub-division of the metamorphic area into zones based on one type of rock is not applicable to the area as a whole.

Another point in which the metamorphism of the Galloway district differs from that of Skiddaw and Barr-Andlau is the comparative rarity of the aluminous orthosilicates. Andalusite and sillimanite occur, but never in such abundance as to form a striking feature of the metamorphic aureoles. This is doubtless due to the fact that pure argillaceous sediments are comparatively rare. The composition of the rocks in most cases admitted of the development of complex silicates, such as garnets and micas.

Before proceeding to give an account of the altered rocks, it will be desirable to offer some remarks on the minerals of which they are composed.

Biotite is unquestionably the most characteristic mineral. Its presence is one of the earliest indications of an approach to the

* Die Steiger Schiefer und ihre Contactzone an den Granititen von Barr-Andlau und Hohwald. Strasbourgh, 1877.

granite, and it gives rise to the purplish brown tint which previous observers have referred to as especially characteristic of many of the altered rocks. In the earlier stages of alteration it occurs in irregular scales, and, as the metamorphism advances, the individuals increase in size. The usual colour is reddish brown, and the pleochroism is intense. The mineral is found in almost all the altered rocks, whatever their original character may have been. Thus it occurs in the grits, greywackes, slates, shales, igneous rocks, and even in the radiolarian cherts. The individuals are usually irregular in outline, and several often occur together. Sometimes the rocks have a spotted appearance, due to local aggregations of biotite.

M. Michel Lévy has especially directed attention to the contrast in the mode of occurrence of the biotite in igneous rocks and altered sediments. In the former it belongs, as a rule, to the earlier stages of consolidation, and consequently exhibits a considerable amount of idiomorphism; in the latter it is interfered with by quartz, and often acts as a kind of paste in which the other constituents are embedded. This feature is illustrated by the biotite of the rocks now under consideration, especially in those which do not exhibit the highest grades of metamorphism. The biotite of the contact rocks, like that of the igneous rocks, often shows pleochroic halos round minute inclusions.

White mica, though not so abundant as biotite, is frequently present. It is usually similar in form and size to the biotite. In some of the highly metamorphic rocks it occurs in large patches, showing micro-poikilitic structure in consequence of the presence of rounded inclusions of quartz (2203), graphitic matter (6602), and other substances.

Quartz.—In the grits, greywackes, and shales, silica is present either as grains or granular aggregates of quartz. In the cherts it occurs in the crypto-crystalline or chalcedonic condition. As the coarser forms of sediment are traced into the metamorphic zone the original outlines of the clastic grains become more or less obliterated. Even in highly altered rocks containing much biotite, indications of the original clastic structure may often be seen, owing to the presence of individual grains or aggregates of quartz, which are much larger than the constituents of the matrix. In all such cases there is, however, a want of definiteness about the boundaries. The peripheral portions of the quartz grains have been affected by the agencies which have recrystallised the matrix.

The change in the chalcedonic silica of the cherts is of special interest. The crypto-crystalline condition passes gradually into the micro-crystalline condition, and this again into a coarsely crystalline condition in which the individual grains measure one or two mm. in diameter. The large individuals in the coarse-grained quartz rocks, which represent the extreme phase of the alteration of the cherts, are very irregular in outline. The junctions of the contiguous grains are of the kind for which Professor Blake has proposed the term "sutural," because they remind one

of the sutures which separate the different bones of the skull. It appears, therefore, that in highly siliceous rocks, such as the cherts, adjacent individuals coalesce to form larger individuals under the influence of contact metamorphism.

Another mode of occurrence of quartz is seen in those rocks which contain minerals having a pronounced micro-poikilitic structure. In these cases the quartz forms minute isolated inclusions with rounded outlines in the containing mineral.

The main facts with regard to the mode of occurrence of quartz in the metamorphic rocks may thus be summarised. In the altered grits and greywackes it occurs as irregular grains and granular aggregates of considerable size in a matrix largely composed of small grains associated with biotite; in the intermediate phases of the alteration of the cherts, and in some other rocks, it forms a mico-crystalline mosaic; in the final stages of the alteration of the cherts it forms coarse-grained aggregates with sutural junctions; and in the micro-poikilitic minerals it occurs as minute rounded grains.

Felspar.—In many cases the felspar, which is abundant in the grits and greywackes of the original rocks, appears to have been altered in the manner described by Messrs. Allport and Bonney. The original grain appears to have been replaced by crypto-crystalline or micro-crystalline aggregates of a mineral which is presumably quartz and minute flakelets of a white mica. Bearing in mind the tendency which felspars have to a micaceous type of decomposition, it is, however, possible that this change may not be due to the effect of contact action upon fresh felspar, but rather upon felspar already attacked by the surface agencies. At anyrate water-clear felspar certainly occurs in many of the highly altered rocks in association with quartz and biotite. A good example of this mode of occurrence is furnished by a specimen taken from a point south of Craiglee Hill, near the head of Loch Doon (2549). The rock is fine-grained and of a dark purplish colour. It is essentially composed of the ubiquitous brown mica and a mosaic of quartz and felspar. A mineral somewhat doubtfully referred to andalusite, and a few grains of iron-ore, also occur. In this case, and in many others of a similar character, there is no reason to regard the felspar as due to impregnation by the granite magma. There are often cases, however, of a more doubtful character, and some in which an intimate intermixture of granite and sedimentary material has undoubtedly taken place. The latter occur on a small scale, and only in the immediate neighbourhood of the contact. A junction specimen from the north-west slope of Meikle Craigrarson (4968) may be cited as an illustration. It consists of a medium-grained aplite in contact with the brown resinous quartz-rock which represents the extreme phase of alteration of radiolarian chert. When examined with a hand lens detached fragments and isolated grains of the characteristic quartz of the chert may be seen lying in the mass of aplite, and the material of the aplite can also be seen insinuating itself between the quartz

grains in the altered chert. Under the microscope these phenomena are still more marked. In that portion of the slide which is mainly composed of altered chert somewhat cloudy orthoclase occurs, moulded on the larger quartz grains which represent the chert. In the other portion of the slide, which is mainly formed of aplite, detached grains and fragments of the altered chert may be recognised. The quartz of the altered chert and that of the aplite can easily be distinguished from each other under the microscope, in consequence of the minute inclusions of biotite which occur exclusively in the former. In this case there can be no doubt that the felspar of the altered rock has been derived from the granite magma.

In the case above referred to, the felspar is orthoclase, but in a few abnormal rocks from the immediate neighbourhood of granite masses plagioclase has also been observed. Its mode of occurrence is quite different from that of the orthoclase just described. Instead of occurring in interstitial patches it behaves rather as a porphyritic constituent. The individuals are often zoned and idiomorphic, and closely resemble the plagioclase of the granite rocks.

M. Michel Lévy has called special attention to the "felspathisation" of the rocks into which granite has been intruded, and he appears to regard the felspar in all cases as foreign to the rock into which the intrusion has taken place. The contact zones surrounding the Galloway granites certainly do not furnish illustrations of such felspathisation on any large scale In many cases the felspar has doubtless been formed out of the constituents of the original rock, and in the few in which it has been introduced the action has occurred only in the immediate neighbourhood of the granite.

Andalusite.—This mineral, including its variety chiastolite, is by no means characteristic of the contact zones. It has been observed only in a few localities. The fact is undoubtedly to be accounted for by the comparative rarity of the purer forms of argillaceous sediment. Miss Gardiner has recorded the occurrence of typical chiastolite in the altered shales of Knocknairling Hill. Here it sometimes forms a conspicuous feature on the weathered surfaces of the rocks and crystals measuring an inch or more in length may be obtained. The mineral also occurs in the altered black shales near the granite contact on Meikle Craigrarson. Here it forms long slender prisms, which are idiomorphic in the prismatic zone. Under the microscope they are seen to be often more or less replaced by aggregates of a white mica, and to contain inclusions of graphite. These inclusions are not abundant, and they are not aggregated in the central portions of the crystals, as is so commonly the case with the black inclusions in chiastolite. Typical chiastolite occurs in black shales containing graptolites, near Black Gairy, Buchan Hill, Glen o' Trool, on the west side of the Loch Dee mass.

Sillimanite.—This mineral has been recorded by Miss Gardiner in the highly altered rocks of Knocknairling Hill. It

occurs in long slender needles, which are sometimes aggregated in clots. As a rule the needles occur as inclusions in the mica and quartz. The rocks of Knocknairling Hill show a higher grade of metamorphism than that observed in any other district, and up to the present this is the only locality in which sillimanite has been recorded.

Garnet.—Red garnets, which are, however, almost colourless in thin sections, are extremely common both in the altered shales and grits. In fact, next to biotite, garnet is the most characteristic contact mineral in the rocks surrounding the Loch Dee and Cairnsmore of Fleet masses. It occurs in grains and idiomorphic crystals of the usual form. The individuals increase in size as the junction is approached. The largest are to be found in the highly altered grits of Knocknairling Hill, in which sillimanite occurs. The central portions are usually crowded with inclusions of a colourless substance, possibly quartz, of irregular form, but usually with more or less rounded contours. Occasionally mica flakes and needles of sillimanite also occur as inclusions in the garnet.

Garnet is by no means limited to the immediate neighbourhood of the granite. It is one of the first minerals to form. In tracing the chert-shale series from the unmetamorphosed area towards the granite the shaly streaks and partings are seen to become crowded with small garnets before any notable change has taken place in the chert. Garnets may be seen in the altered shale and radiolaria in the chert of the same slide. A good example of this is furnished by a specimen from Polmaddy Burn, five miles W.S.W. of Carsphairn (4956).

Graphite.—The unaltered rocks belonging to the chert-shale series are often highly charged with carbonaceous matter in the form of fine dust. In the neighbourhood of the granite masses this is converted into crystalline aggregates and plates of graphite, giving brilliant reflections when viewed under suitable conditions. The graphite may be easily isolated by treating the powder of the rock with cold hydrofluoric acid for some days, and then washing the residue. The comparatively light graphite is readily separated from the heavier undecomposed particles. It occurs for the most part in irregular crystalline aggregates, measuring on the average about ·03mm. in diameter; but extremely thin plates are by no means uncommon. These show brilliant metallic lustre in ordinary reflected light or when viewed with a lieberkuhn, and hexagonal outlines, though rare, may occasionally be seen. In a specimen (4969) from Meikle Craigrarson, which illustrates this mode of occurrence of graphite in great perfection, quartz and graphite are the two principal constituents, but thin layers containing long slender prisms of chiastolite also occur. White mica is present in small quantity, and minute crystals of tourmaline and rutile have also been recognised. The quartz forms a somewhat coarse micro-crystalline aggregate. The individuals are polygonal in

outline, and generally contain numerous minute opaque inclusions, probably also graphite, in their central parts.

It is tolerably certain that the original rock was a carbonaceous chert containing thin partings of shale. In the process of metamorphism the original minute particles of carbonaceous matter coalesced so as to form crystals and crystalline groups of graphite; the molecules of silica in the chert also coalesced to form the crystalline aggregate of quartz, and the argillaceous particles of the shale furnished the material for the crystals of chiastolite.

A similar development of graphite has been described by Beck and Luzi* in Saxony.

The other minerals which have been observed in the contact rocks surrounding the Galloway granites may be very briefly disposed of. *Pyrite* occurs both in the unaltered and altered rocks. Opaque iron-ores are also often present. *Rutile* is found in the form of slender needles in the unaltered slates and shales and as yellow crystals and grains in some of the altered rocks. The development of rutile in the form of yellow crystals and grains at the expense of the needles which so commonly occur in the clay slates has been described by Beck. *Tourmaline* is rare as a contact mineral, but yellow and blue varieties occur in some of the altered shales of Knocknairling Hill. *Hornblende* and *augite* are also rare. Radiating prisms of colourless *tremolite* have been observed in some small lenticles associated with the altered shales of Knocknairling Hill, and a pale green fibrous hornblende occurs in a compact hornstone-like rock associated with the normal biotite-hornfels of Barclay Hill, on the southern side of the Criffel mass. At the last-mentioned locality we find also an abnormal felspar-bearing contact-rock containing large patches of micro-poikilitic greenish or greenish-brown hornblende. It is possible, however, that in this, as well as in some other cases in the immediate neighbourhood of the granite contact, where similar hornblende occurs, the rock may be of mixed origin, and not simply the result of the crystallisation of an original sediment. Granular pyroxene has been observed in a rock from the immediate neighbourhood of the contact, about a quarter of a mile north of Kells Farmhouse, near Southwick. The rarity of silicates containing lime and magnesia is doubtless due to the fact that the district is comparatively free from calcareous sediments.

ALTERED SEDIMENTARY ROCKS.

In the study of contact-metamorphism it is obviously of great importance to trace step by step the alteration of particular

* Ueber die Bildung von Graphit bei der Contactmetamorphose. Neues Jahr. (1891). Vol. ii., p. 28. See also Erlauterungen zur geologischen Specialkarte des Königreichs Sachsen, Section Pirna.

beds of rock of known composition from areas where they have not been affected by the igneous rock up to the actual contact. Over a large portion of the district this is attended with considerable difficulty in consequence of the absence of continuous exposures and the variable nature of the coarser forms of sediment which make up so large a portion of the area.

That the grits and greywackes pass into crystalline rocks, in which the original clastic structures are either partially or wholly obliterated, can be easily demonstrated, but to trace any one bed of grit from the unaltered area to its actual contact with the granite is impossible. Under these circumstances the occurrence of a well-marked zone, such as that of the radiolarian cherts and shales, is of the greatest importance. It maintains its uniform character over the whole district, and may be traced at intervals, without any possibility of error, from the unaltered area up to the junction with the granite. Mr. Horne in 1892 called attention to these facts in a communication to the Geological Section of the British Association at Edinburgh, and also described the microscopic characters of the altered rocks. The following account of the metamorphism of the rocks of this zone is based mainly on the specimens which he collected on the eastern side of the Loch Dee mass.

The unaltered chert, of which specimens may be obtained in the Garryhorn Burn, below the Lead Mines, Carsphairn, is a dark, sometimes almost black, rock (6998), traversed by narrow white quartz veins. If the surface be moistened and examined with a lens, the black portions are seen to occur in patches and extremely thin veins. Under the microscope the rock is seen to be mainly composed of clear, crypto-crystalline silica, in which the circular and elliptical outlines, indicative of the former presence of radiolarian tests, are easily discernible. The silica filling the tests is somewhat coarser in crystalline texture than that forming the main mass of the rock. It differs also in another respect. The interstitial chert, when examined with a high power, is seen to be less pure. It contains minute grains and flecks, and here and there minute flakes of a colourless micaceous mineral may be detected. In addition to the crypto-crystalline silica and the impurities above referred to, the clear chert contains two or three isolated rhombs of a carbonate. The material which gives the dark colour to the rock occurs partly in thin veins and partly in the mass of the rock in the neighbourhood of the veins. It is in these turbid portions of the slide that the lattice-structure and spines of the radiolarian tests are preserved. In parts of the slide the actual substance of the tests has evidently been replaced by the opaque material. The white quartz veins are filled with micro-crystalline silica with which some black opaque material is occasionally associated. The following analysis has been kindly made for us by Mr. J. Hort Player:

Silica,	91·3
Alumina,	3·3
Ferric oxide,	·7
Ferrous oxide,	1·4
Lime,	trace.
Magnesia,	·8
Soda,	·2
Potash,	·6
Loss by ignition,	·9
	99·2

As this rock is followed towards the granite it becomes light brown or grey in colour, and takes on the character of a fine-grained quartzite. The granular structure becomes coarser as the granite is approached, and in the immediate neighbourhood of the contact the rock is often an extremely coarse-grained aggregate of quartz, having a brown colour and a peculiar resinous lustre.

The series of microscopic slides (4953-4969) illustrates in a very perfect manner the gradual passage from compact chert to coarsely crystalline quartz-rock. In the unaltered rock the individual crystalline particles are so small as to overlap in the thinnest possible sections, and from this condition to one in which the rock is mainly composed of grains of quartz, measuring one to two millimetres in diameter, every immediate stage may be observed. The crypto-crystalline condition passes gradually into the micro-crystalline condition, and this again into the coarsely crystalline condition. The change is accompanied by the development of brown mica. This mineral first appears in the form of extremely minute scales in the more or less impure chert which fills up the space between the radiolarian casts. The purer silica, of which the circular patches are formed, did not contain the material necessary for the building up of mica. As a consequence of this it sometimes happens that the traces of radiolaria are more conspicuous in the rocks which have been slightly altered than in those which lie outside the zone of metamorphism. In the final stages all traces of the radiolaria are lost, and the larger grains contain rounded flakes of biotite, usually measuring from ·03mm. to ·05mm. in diameter. In addition to the small isolated and more or less rounded flakes of biotite which occur as inclusions in the quartz, we find also a few ragged flakes which attain larger dimensions. In describing the microscopic appearance of the most highly altered forms of radiolarian chert, attention was especially called to the brown resinous aspect. Microscopic examination shows that this is due to the innumerable minute inclusions of biotite contained in the quartz. The two characteristic minerals of the altered representatives of the chert are quartz and biotite, and the rocks therefore constitute a special type of biotite-hornfels. In addition to the two characteristic minerals, we find occasionally

small garnets, ill-defined and often fibrous greenish products, probably arising as a consequence of the alteration of the rhombs of carbonate which occur sparingly in the unaltered rock. At the actual granite-contact, as in the specimen from Meikle Craigrarson already referred to, the coarse-grained quartz rock becomes more or less disintegrated, and detached grains of quartz, with the characteristic inclusions of biotite, may be isolated in the igneous matrix. A specimen of the coarse-grained quartz-biotite-hornfels from the immediate neighbourhood of the granite, collected at a point about 1½ miles S.S.W. of Meaul, has also been kindly analysed by Mr. Player:

Silica,	93·3
Alumina,	3·1
Ferric oxide,	·4
Ferrous oxide,	·8
Lime,	·1
Magnesia,	·4
Soda,	·3
Potash,	·8
Loss by ignition,	·3
	99·5

A comparison of the two analyses shows that there has been no appreciable change in chemical composition produced by the intrusion of the granite, except, perhaps, in the reduction of the amount of volatile matter. The two analyses do not differ more than two analyses of the unaltered chert may be expected to differ. The analysis of the unaltered chert clearly proves that the impurities, as they may be termed, are capable of forming brown mica.

The only effect of the granite intrusion upon the chert is thus proved to be a molecular rearrangement of the chemical constituents. The molecules of silica coalesce to form large irregular grains of quartz, and at the same time the molecules of alumina, iron-oxide, magnesia, and alkalies combine with silica to form small scales of biotite. The actual distance traversed by any molecule during the recrystallisation of the rock is extremely small, probably not greater than the diameter of one of the mica-flakes.

The shales associated with the cherts also undergo important alteration, and in consequence of their more complex composition give rise to a greater variety of contact minerals. In their unaltered state they consist largely of extremely minute scales of a colourless or nearly colourless mica, associated with very small grains of quartz and felspar (?). Pyrite in cubes and patches, carbonates, and black carbonaceous matter are often present. A specimen from the highest exposure in Polmaddy Burn, about a mile from the granite junction (4956), illustrates one of the early stages of metamorphism of the chert-shale series.

The rock has been more or less brecciated, and the chert and shale kneaded together. The chert has been very slightly affected; much of it still remains in the crypto-crystalline condition, and the impurities have not as yet given rise to brown mica. Radiolaria are clearly recognisable. Important changes have, however, taken place in the bands and wisps of shale. At the junction of the two rocks a large number of small garnets have been developed. These are sometimes so thickly crowded together as to mutually interfere with each other; at other times they are isolated and idiomorphic, the intervening space being rich in secondary brown mica. The individuals vary in size from about ·02mm. to ·05mm. in diameter. The alteration in the central portions of the shale bands is not so marked, but here, also, garnet and brown mica have been formed. This exposure clearly proves that the shale is more readily affected by the metamorphic agencies than the chert, doubtless in consequence of its more complex composition. A further stage in the alteration is illustrated by a specimen from a point on the ridge which separates Meaul and Carlins Cairn, about 300 yards east of the granite junction (4958). In this case the chert has become distinctly granular, resembling a very fine-grained grey quartzite, whilst the shale has been converted into a compact hornfels containing numerous small dark spots. Under the microscope the hornfels is seen to be composed of brown mica and quartz. The spots are formed of irregular individuals and aggregates of a doubtful mineral full of small more or less rounded grains of quartz. The brown mica occurs in the form of small scales which, together with quartz, make up the greater part of the space between the spots. When viewed in ordinary light the spots are distinctly visible in the thin section in consequence of the rarity of biotite. In addition to the minerals above mentioned, which make up the greater portion of the rock, we find also a few flakes of white mica.

The extreme phase of the alteration of the shales is represented by a specimen from the Kirreoch Burn, about one mile west of Carlins Cairn. In external appearance it is a dark brown mica-schist. The microscopic section (7000) shows that the rock is formed of lenticles of altered chert, separated by portions of altered shale. The latter consist of brown mica, quartz, and greenish aggregates of a micaceous mineral which probably represent andalusite. The brown mica in this case occurs in much larger flakes than in the rock last described. The analysis of this rock by Mr. Player gave the following result:

Silica, ...	64·3
Titanic acid, ...	1·1
Alumina, ...	15·8
Ferric oxide, ...	1·3
Carry forward, . .	82·5

Brought forward, . . .	82·5
Ferrous oxide, ...	6·9
Lime, ...	·5
Magnesia, ...	2·8
Soda, ...	·8
Potash, ...	3·7
Loss by ignition, ...	1·8
Sulphuric anhydride, . . .	·4
	99·4

The Survey Collection includes a few rocks of special interest from the chert-shale horizon, which deserve detailed description. The specimen from the neighbourhood of the granite on Meikle Craigrarson (4969) is a thin slab measuring about three-eighths of an inch in thickness and of a dark bluish-grey colour. Long slender prisms of chiastolite may be easily recognised on the flat surfaces by means of a pocket lens. The microscopic section shows that these crystals do not occur in the mass of the rock, which is mainly composed of a granular aggregate of quartz and crystalline graphite, but only on the surfaces and in narrow bands. The original rock was doubtless composed of a carbonaceous chert interlaminated with shale, and the chiastolite has been formed in the latter. The chiastolite gives approximately rectangular cross sections, and has been more or less replaced, especially at the margins, by vividly polarising aggregates of white mica. In addition to quartz, graphite, and andalusite, the rock also contains both white and brown micas, but not in any quantity.

Specimens from the opposite side of the granite mass, about five-twelfths of a mile from the granite junction, west of Black Gairy, Buchan Hill, Glen of Trool (4983 and 4984) illustrate an early phase of the alteration of black shale containing graptolites. The rock is a bluish-black hornfels, containing much pyrite, partly disseminated through the mass and partly collected in veins. The mass of the shale is crowded with fine black carbonaceous particles, which have not formed definite scales of graphite as in the rock last described. Slender prisms of chiastolite are recognised both in the hand specimen and under the microscope. A second mineral has also been developed, but it is now only represented by a brown alteration product, giving aggregate polarisation, and its original character cannot be determined.

The alteration of the grits and greywackes can only be described in general terms. The first stage is seen in the development of small flakes of brown mica between the clastic grains of quartz and felspar (6599). The mica flakes increase in size and abundance as the metamorphism advances, and they are developed not only in the matrix but also in the included rock fragments. The outlines of the original clastic grains become confused and vague, and finally in the most highly altered rocks,

such as those at Knocknairling Hill, no trace of the original structure remains. Brown mica is the most characteristic contact mineral. It occurs in irregular scales, several of which usually occur together. As a rule, it is markedly allotriomorphic with respect to the quartz; in other words, it plays the rôle of interstitial matter. In some cases, however, it occurs in inclusions in the quartz grains in detached and usually rounded scales.

The grits and greywackes show great variability in the size of their constituent particles. This feature is seen in all except the most highly altered rocks. As the metamorphism increases the outlines of the fragments become more or less vague and indistinct, but their former presence is clearly indicated by the occurrence of patches rich and poor in brown mica.

Of the original constituents felspar is perhaps the most important after quartz. This mineral appears to be sometimes destroyed and sometimes regenerated in the process of metamorphism. It is very frequently represented, as Messrs. Bonney and Allport pointed out, by micro-crystalline aggregates, associated with ill-defined flakelets of a micaceous mineral. At other times it appears cloudy, but with individual action on polarised light, and in a few cases it is present as a water-clear mineral in connection with quartz (2549). In addition to the mineral fragments, the grits and greywackes frequently contain bits of felsitic, trachytic. and andesitic rock, fragments of shale and fine grits, and occasionally radiolarian chert. It is not possible to trace step by step the alteration of the different varieties of rock, and we are, therefore, often in doubt as to the original character of some of the fragments in the highly altered strata. However, the felsitic fragments may frequently be recognised in the metamorphic rocks (690), and they show that here and there small flakes of the ubiquitous brown mica have been developed even when the micro-structure of the main mass has been little, if at all, changed. The andesitic fragments lose their characteristic structure and give rise to much brown mica. The shale fragments also show a great development of brown mica, with which some white mica is occasionally associated.

So far we have been referring only to rocks that surround the most northern of the three large granite masses. The greywackes and grits rarely lose all trace of clastic structure, even when the recrystallisation is complete. A higher grade of metamorphism appears to be reached on the borders of the Cairnsmore of Fleet mass, in the neighbourhood of New Galloway. The altered rocks of this area have been microscopically examined and described by Miss Gardiner, and the result of the examination of the material collected by the Geological Survey has merely served to confirm the accuracy of her work. A series of fine-grained grits and shales can be followed at intervals from a comparatively unaltered condition to one in which complete recrystallisation has taken place. The more argillaceous members of the stratified series pass into chiastolite-schists, and can be followed close up to the junction with the granite. These

rocks do not present any features of special interest. The alteration of the gritty beds is more remarkable. The final product is a coarse-grained gneissose rock, mainly composed of brown mica, quartz, sillimanite, and a little felspar, without a trace of the original clastic structure. Such a rock may be termed a gneissose garnet-sillimanite hornfels with two micas. The general appearance of the rock under the microscope is well represented in Fig. 2, Pl. XXIII., illustrating Miss Gardiner's paper. Although specimens may be obtained of somewhat coarser texture, the Survey specimen (6604) may be taken as a type of this rock. In the hand specimen it is a dark, medium-grained, foliated rock. White mica is conspicuous on the surfaces parallel to the foliation. Notwithstanding the fact that the white micas are arranged with their flat surfaces approximately parallel to each other, the rock does not cleave readily in the direction of foliation. Under the microscope white mica is the most conspicuous mineral. It occurs in ragged plates, which often contain garnet, quartz, and sillimanite as inclusions. Single individuals, measuring one or two millimetres across, are not uncommon. The plates are sometimes isolated, but more frequently two or three occur together. The biotite also occurs in ragged plates, but the individuals are smaller. The pleochroism is strongly marked, and in the position of maximum absorption the mineral appears a very dark brown. Pleochroic halos are present. Garnet occurs in the form of rounded and irregular grains, and also as idiomorphic crystals. The individuals vary in size, those measuring about ·3mm. in diameter being very common. In other specimens of the same rock the average size is larger. Inclusions of a colourless mineral, probably quartz, are usually numerous, especially in the central portions of the mineral. The mineral appears red in the hand specimen, but in the thin sections is nearly colourless. The sillimanite is developed in the form of very fine needles, which are often aggregated in tufts. They are especially abundant in the white mica, but occur also in the quartz. Quartz occurs in irregular grains, and sometimes forms a coarse micro-crystalline mosaic. Felspar is rare. It may be recognised by its refractive index, which is lower than that of the balsam in which the slide is mounted, by its biaxial figure, and by the occasional presence of lamellar twinning.

As this rock is traced away from the granite, a marked diminution in the size of the white mica is observed. A good illustration of this is furnished by a specimen from a point below the Cairns and near the stone dyke (6605). The rock is a garnetiferous mica-schist. The schistosity is more marked than in the specimen from the immediate neighbourhood of the granite, and the white micas, instead of appearing as individual plates, form a glaze on the flat surfaces. The garnets are, however, somewhat larger in this specimen than in the last.

In the immediate neighbourhood of the granite the garnet-

sillimanite hornfels contains lenticles of a pink rock essentially composed of quartz and garnet.

The alteration of the shale bands into more or less schistose rocks containing chiastolite has been already referred to. Associated with these shales are some thin bands and lenticles of a harder rock, in which radiating groups of crystals may be recognised with a hand lens (6601). Under the microscope these crystals can be identified as tremolite. The other minerals recognisable are quartz, mica, pyrite (abundant), and black carbonaceous dust.

In the immediate neighbourhood of the granite occurs a black graphitic schist (6602), containing micro-poikilitic white mica crowded with minute particles of carbonaceous matter, and not easily distinguishable from the main mass of the rock, which consists mainly of quartz and carbonaceous dust, without the aid of polarised light.

It appears from what has been already said as to the contact-metamorphism surrounding the granite masses of Galloway that the district abounds in illustrations of the alteration of the various types of non-calcareous sediment. Limestones are, however, conspicuous by their absence from the contact zones. Under these circumstances special interest attaches to a compact green rock occurring in impersistent bands and lenticles in a biotite-hornfels, close to the junction of the Criffel mass, on the south-east of Barclay Hill, about $4\frac{3}{4}$ miles S.S.E. of Dalbeattie. This rock (6598) probably represents in an altered form one of the impure calcareous rocks associated with the Upper Silurian deposits of this area. It is the "corne verte" of French petrographers. Under the microscope it is seen to be a very fine-grained aggregate of a colourless mineral, presumably quartz, hornblende, a colourless garnet occasionally showing signs of double refraction, and some opaque grains of iron-ore. The hornblende is allotriomorphic, and the larger patches show micro-poikilitic structure. All the constituents are extremely small, and the true character of the rock can only be determined by the use of very thin sections and a high power. It would be interesting to determine whether any felspar is present, but owing to the extremely fine grain of the rock this is impossible.

We have now to describe the effects of the granites upon the igneous rocks of Lower Silurian age.

ALTERED IGNEOUS ROCKS.

Arenig lavas altered by granite occur near New Cumnock and at the margin of the Carsphairn mass. Those from the former locality (6530-6538) are coarse-grained, massive, and often mottled with dull green and pink tints. Traces of an amygdadolial structure may frequently be seen in the hand specimens.

When examined under the microscope the mineralogical composition of the rocks is seen to vary in different specimens, and even in different portions of the same section. The following

minerals have been recognised in the series taken as a whole: hornblende, augite, biotite, garnet, felspar, sphene, epidote, black opaque iron-ores, pyrite, hæmatite, carbonates, chlorite.

The hornblende is usually brown, but green varieties have also been observed. It occurs in small crystals, with more or less rounded angles; also as grains and as large micro-poikilitic patches crowded with small felspars and other minerals (6531). The augite is pale in colour and faintly pleochroic in pale green and violet-brown tints. It is usually present in the form of small grains and irregular patches, but traces of the ortho-pinacoid, clinopinacoid and prism faces have been observed.

The common type of biotite is greenish in colour. It may be present either as small scales or as large micro-poikilitic patches. The reddish brown biotite, which is so common as a product of contact-metamorphism, has been observed only in one specimen (6538). Here, however, it occurs in great abundance, and forms, together with felspar, the main mass of the rock.

Garnet is especially characteristic of the series, taken as a whole, although it is not present in every specimen. This mineral is found in the mass of the rock, and also in veins and amygdaloidal cavities. It may be deep brown or colourless, and it is worthy of note that the colourless varieties invariably show double refraction. Pale brown varieties are the most common. The individuals are aggregated together, and but rarely show signs of idiomorphism. They frequently form zones round the amygdaloidal cavities, and sometimes extend into these cavities. In the latter case they increase in size, lose their colour, become doubly refractive, and sometimes idiomorphic. It is interesting to note that the garnet of these rocks is quite distinct from that of the altered grits and shales. On the other hand, it resembles the garnet often found in metamorphosed calcareous rocks. It is highly probable that it has been developed only in those rocks which were decomposed before the intrusion of the granite, and in which carbonates had been extensively developed.

Felspar occurs either as aggregates of irregular grains or as large micro-poikilitic patches. The latter are certainly orthoclase. The substance of this felspar, which forms as it were the ground mass of several specimens and shows uniform extinction over large areas, is often perfectly limpid and entirely devoid of twinning, but it is so closely crowded with the other constituents of the rock that its exact determination is attended with considerable difficulty. The fine powder of the rock was searched for a long time in the hope of finding minute M-flakes, but no reliable results were obtained. A solution of borotungstate of cadmium, having a refractive index intermediate between that of orthoclase and albite, was then prepared. When tested in this solution by the Becke-method, the mineral in question was found to agree with the orthoclase, and at the same time one or two M-flakes were accidentally met with. These gave confirmatory evidence. Seeing that the original rocks were either intermediate or basic in composition there can be no doubt that

this felspar is a product of metamorphism. This, indeed, might be inferred from its relation to the other constituents quite apart from its composition. Further evidence of the secondary development of felspar is furnished by the fact that it may occasionally be observed in the amygdules. In addition to the secondary felspar, which is always present, one specimen contains the relics of felspar-phenocrysts. These are zoned by garnets which appear to eat into and partially occupy the space originally filled with felspar.

Sphene is almost always present in considerable abundance. It occurs in the form of minute colourless grains, often clustered together, and, more rarely, as larger grains, which sometimes assume a spindle-shaped form.

Iron-ores, zoned with colourless sphene, may be observed in one or two specimens.

Epidote is not a common constituent. It may occasionally be seen associated with a carbonate in the central portions of some of the amygdules. Carbonates, when present, occur as large crystalline patches moulded upon the other constituents. They probably represent the secondary carbonates, due to the decomposition of the original rocks; but, if so, it is clear that they must have undergone recrystallisation under the influence of the granite. The other minerals do not call for detailed description.

With the exception of the felspar phenocrysts in one specimen (6530), and the amygdaloidal structures in several others, the original structures of these rocks have entirely disappeared. The augite, hornblende, garnet, sphene, and the greater part of the felspar are of secondary origin, and they have been developed in such a way as to destroy the original micro-structure of the rock. The only rocks in any way resembling those above described are the metamorphosed basic rocks surrounding the shap granite (See Quart. Journ. Geol. Soc., vol. xlix. (1893) Supplementary Notes on the Metamorphic Rocks around the Shap Granite: by Messrs. Harker and Marr). The two groups resemble each other in containing garnet of the same type, sphene, augite, and hornblende, but the micro-poikilitic orthoclase, which forms a peculiar feature in many of the Scottish rocks, is absent from those of Shap.

The following table represents the distribution of the minerals in the specimens from Polshill Burn:—

[TABLE.

ALTERED ARENIG LAVAS.

	Hornblende.	Augite.	Biotite.	Garnet.	Orthoclase.	Felspar (?)	Sphene.	Epidote.	Iron-ores.	Carbonates.	Chlorite.	Aggregates of a colourless undetermined mineral.	
6530				×	×	?	×	×	×	×	×		Amygdule filled with carbonate and epidote and zoned with garnet. Felspar phenocryst zoned with garnet.
6531	×	×	×	×	×		×		×			×	Orthoclase in large water-clear untwinned micro-poiklitic patches. Iron-ores zoned with sphene.
6532		×	×	×	×		×	×				×	Orthoclase as above.
6533			×	×	×		×		×		×		Pyrite.
6534	×	×	×	?	×	×	×		×				Micro-poikilitic hornblende.
6535	×	×		×	×		×			×		×	Orthoclase as in 6531. Garnet often doubly refractive.
6536	×	×	×	×	×		×					×	Orthoclase as in 6531, sometimes crowded with granular pyroxene.
6537			×	×	×	?	×		×	×	×		Secondary felspar in amygdules.
6538			×			×			×				Pale brown and pale green biotite in small scales. Micro-crystalline aggregate of felspar.

The altered Arenig lava from the edge of the Cairnsmore of Carsphairn granite (7171) is composed of small whitish spots and patches with somewhat vague boundaries in a fine-grained dark matrix.

Under the microscope the whitish spots are seen to represent, at any rate in most cases, amygdaloidal cavities. The central part of the spot is usually occupied by a patch of crystalline calcite with irregular borders. The marginal part is an aggregate of felspar. The crystalline calcite is moulded on the felspar. Granules of colourless sphene and crystals or grains of epidote occasionally occur in association with the calcite and felspar; so also do malacolite, hornblende, and garnet, though more rarely. The ground-mass is essentially composed of felspar and hornblende. These two minerals form a confused aggregate. The individuals of hornblende are small, and without any marked idiomorphism, although they frequently show a tendency to elongation in the direction of the vertical axes; they are not large enough to show good cleavages. The colours are: α, yellow; β and γ, olive-green. The hornblende lies in a matrix of felspar which cannot be definitely determined. Definite crystallographic boundaries are absent, but the individuals sometimes show a tendency to elongation in one direction. Colourless grains of epidote or malacolite also occur in association with hornblende and felspar. Grains and crystals of sphene may also be occasionally observed. From the above description it appears that the original rock has been recrystallised, and the true igneous structure has been almost entirely obliterated in the process.

Another specimen from Poldores Burn, Carsphairn (7172), is a medium-grained, dark, massive rock, composed of lath-shaped plagioclase, ophitic brown hornblende, biotite, and iron-ores.

The original rock was doubtless an ophitic dolerite, probably intrusive. The augite has been changed to dull brown hornblende without well-marked cleavages. Large patches extinguish uniformly, and bear the same relation to the lath-shaped felspar as the augite of the original rock. Biotite occurs in aggregates of small scales, which are not distributed uniformly throughout the rock. This rock differs from the last in that the original structure has been largely retained.

CHAPTER XXVIII.

ECONOMIC PRODUCTS OF THE SILURIAN ROCKS OF THE SOUTH OF SCOTLAND.

In this chapter attention is directed to the economic products of the Silurian strata of the Southern Uplands and the associated igneous rocks, which are presumably older than Upper Old Red Sandstone time.

Building Materials.—Throughout the uplands, the Silurian rocks furnish several varieties of building stone. In particular, the massive greywackes and grits of the Central Belt (Llandovery and Tarannon) are locally used for this purpose on account of their durability and regular system of jointing, the corner stones and facings for windows and doorways being usually composed of sandstone of Triassic, Permian, or Carboniferous age. Indeed all the towns and villages within this geographical belt, from Peebles, Galashiels, and Hawick in the east, to Wigtown and Glenluce in the west, are mainly constructed of these materials. In the Northern Belt, also the greywackes and grits (Caradoc and Llandeilo) have been serviceable for building, as, for instance, in the districts of Broughton, Leadhills, Wanlockhead, Carsphairn, and Portpatrick. Most of the houses of the latter seaside resort and the greater part of the pier and dock have been built of stone from the large quarry at Portpatrick. Within recent years, however, since the development of the railway system, the much younger sandstones of Annan, Dumfries, and other localities have been exclusively used for the larger buildings within the Silurian region.

By far the most important building stones are obtained from the granite masses that traverse the Silurian rocks in the south-west of the tableland. The largest quarries have been opened at Dalbeattie and to the south of Creetown. The stone from these places has been extensively used for ornamental purposes, for street pavement, and for docks. The new docks at Liverpool have been entirely constructed of stone obtained from the Creetown granite quarry. Recently the Dalbeattie granite has been used for the manufacture of granolithic pavement.

In the Ballantrae region some of the red, green, and mottled varieties of serpentine, and the beautiful diabase-porphyrite (Arenig lava) of Currarie, Knockgown, Pinbain, and other localities are worthy of attention for ornamental purposes, but they have not yet come into use.

Throughout the Silurian Tableland the greywackes, grits, and flagstones, together with the dykes of acid intrusive rocks, have

been locally available for field "fences" or "dry-stone dykes." The grey and blue flaggy shales have been worked at various localities for roofing purposes, as, for example, at Stobo, Wrae, and Grieston in Peeblesshire, near Elvanfoot in the Abington district, at Benbuie near Moniaive in Dumfriesshire, at Barlae and Marnhoul in the district of the Ken, at Loch Lure and Loch Bradan north of the Loch Doon granite mass, at Cairnryan in Wigtownshire, and other places. They are not genuine slates, as they split along the bedding planes, and on account of their weight are not well adapted for roofing. For many years they have been superseded by the lighter Welsh slates.

Limestones.—These occur chiefly in the Girvan and Ballantrae region, where they are still in much request for agricultural purposes. The limestone occurs in thick beds of excellent quality, and might be extensively employed for more than local use. The largest quarries still in operation are those of Tramitchell and Craighead; within the last few years another opening has been made at the latter locality close to the quarries formerly worked. Other exposures of the Stinchar Limestone at Aldons, Bougang, Colmonell, etc., which were formerly quarried, have now been abandoned. In Peeblesshire thin lenticular patches of limestone occur at Wrae, Glencotho, Drummelzier, and Winkston, the working of which has long been discontinued.

Road-Metal.—The harder greywackes of the Silurian system are extensively used for macadamised roads, but the material is frequently not very durable. The massive greywackes and grits (Llandovery and Tarannon) are best adapted for the purpose. More compact road-metal is obtained from the dykes of microgranite and porphyrite where these are readily accessible, as, for instance, in the neighbourhood of Castle-Douglas, Innerleithen, and the Moorfoot Hills, the exposures of which are indicated on the several sheets of the Survey Map.

Hone-Stones.—In the Dippal Burn in Ayrshire, and at Hareshaw in the Pentland Hills, the green fine-grained shales in the fish-bearing zone of the Downtonian series have been quarried for hones. Some of the softer flags and shales in the Lowther Shales of the Leadhills region might be used for water-hones.

Ores.—*Lead.*—Galena has been worked at various localities throughout the uplands, especially in the districts of Leadhills, Wanlockhead, Blackcraig, near Newton-Stewart, and at Carsphairn. Of these mineral fields the most important is that of Wanlockhead and Leadhills, where mining operations are still in progress. An interesting feature connected with the occurrence of galena in this region is the gradual disappearance of metalliferous conditions as the black shales are approached horizontally and vertically. The ore seems to be restricted there to veins in the arenaceous sediments (Caradoc) overlying the radiolarian cherts and Glenkiln-Hartfell black shales. This peculiarity in the distribution of the galena has been noted at the surface, and has been proved by the mining operations underneath.

The direction of the veins is indicated on the Geological Map of that region (Sheet 15), and their general character may be gathered from the following description of a part of the New Glencrieff vein, given in the Explanation accompanying that sheet. The vein hades to the east at 70°–75°. Beginning at the east or "hanger" side, the order of metals is as under (Explanation of Sheet 15, p. 42):

	INCHES.
a. Greywacke: part of the general Silurian rock or "country."	
b. "Black Jack" (zinc-blende) decomposing into clay, . .	$\frac{1}{4}$
c. "Vein-stuff": greywacke ground up and mixed with quartz,	$1\frac{1}{2}$
d. Calc-spar ($\frac{1}{2}$ inch to 1 inch), ...	1
e. Galena, ...	$\frac{1}{2}$
f. "Vein-stuff," similar to *c*: quartzose and graduating into pure quartz near the floor of the level (2 to 3 inches), .	3
g. Blue greywacke: joints veined with calcareous matter, .	$3\frac{1}{2}$
h. Hard, fine, compact quartz, with iron-pyrites in flowers; that is, the crystals are scattered through the mass and are not connected, ...	7
k. Alternating irregular layers of barytes and galena, . .	8
l. "Vein-stuff," similar to *c*.	
m. Greywacke (the "ledger" side of the vein) marked with vertical slicken-sides,	

The section is about six feet high. A string of "Black Jack" commences at the roof of the level in *g*, and cuts through all the layers to *m*, which it enters near the floor; *a*, *g*, and *m* are "country." The other layers and the string are properly the vein. The veins vary at every step, and are sometimes remarkably rich in lead ores; while, on the other hand, the levels are sometimes driven for many fathoms without meeting with any.

At Dalleagles, south of New Cumnock, a vein of galena occurs close to the great boundary fault, in strata consisting of blue shaly greywackes similar to those at Leadhills.

At Blackcraig, near Newton-Stewart, large mines have been opened in the Llandovery and Tarannon flags and shales and in the underlying black shales, where the veins of galena have a general trend from E.S.E. to W.N.W. A few transverse veins run generally N.N.E. As in the Leadhills region, the galena is here associated with zinc-blende, quartz, and calcite. The same ore of lead has been worked in the Wood of Cree, opposite Penninghame House; at the Cairnsmore Mines, near Cairnsmore House; and at the Pibble Hill Mines, east of Creetown. Further west, thin veins of galena have been found on Knockibae Hill, to the north of New Luce.

Galena was at one time extensively worked at the lead mines at Garryhorn, west of Carsphairn, where the main vein, which traverses greywackes and shales, runs in a north and south direction. This ore of lead likewise occurs there in the greywacke as well as in the main vein.

In the Balloch Burn, below the Nick of the Balloch near the head-waters of the river Stinchar, a trial mine in search of galena was opened in the greywackes and shales.

Among the Upper Silurian rocks of the Lesmahagow inlier, galena occurs in several veins in association with barytes, as, for instance, near the head of the river Nethan and its tributary,

the Pockmuir Burn. One lode, on the north slope of Nutberry Hill, about two feet wide, consists of barytes with a string of galena from two to four inches across. Another lead-bearing vein occurs near the head of the Ponesk Water in the same area (Sheet 23).

Iron.—Thin veins of hæmatite occur in association with the red radiolarian cherts (Arenig) at various localities near the northern margin of the Silurian Tableland, as, for example, not far to the south of Lamancha in Peeblesshire; near Tewsgill in the Abington district, Lanarkshire; below the Nick of the Balloch near the head-waters of the Stinchar in Ayrshire; and on the Salachan Hill in the estate of Knockdolian in the same county. At none of these localities does this ore occur in workable quantity. A specimen of red hæmatitic shale, procured by the Geological Survey from this horizon at Noblehouse in Peeblesshire, was analysed by the late Professor George Wilson, with the following result (Explanation of Sheet 24, p. 23):

Peroxide of iron.	38·42
Alumina, ...	12·19
Clay, ...	44·62
Alkaline salts with traces of lime and magnesia,	4·77
	100·00

Iron, per cent., 27·0.

A prominent vein of hæmatite occurs on the Coran of Portmark, near the eastern margin of the Loch Doon granite mass, the trend of which is about N.N.W. and S.S.E. The direction of this vein has been proved by various trial pits, which show that it traverses the slightly altered greywackes and shales. Thin veins of hæmatite have been noted also (1) on the north shore of Dally Bay, south of Corsewall Lighthouse; (2) in the neighbourhood of Mabie, south-west of Dumfries, near the margin of the Criffel granite mass; (3) in the Glenjaan Burn, north of Moniaive, Dumfriesshire; (4) in association with the lead veins of Wanlockhead and Leadhills; (5) in association with barytes near the head of Pockmuir Burn in the Lesmahagow inlier. Traces of chalybite occur in a vein at Tonderghie, near Whithorn, Wigtownshire, in association with copper pyrites.

Copper.—Veins of carbonate of copper occur in the grits and shales near the village of Elba, below the junction of the Whiteadder with the Dye Water in the Lammermuir Hills. Again, in the Priestlaw granite mass in the same region, copper ore ("green carbonate and prismatic copper glance") is met with in veins of barytes, where they have been worked to a small extent. In the course of the Geological Survey of the Lammermuir Hills various lodes containing copper ore were observed, which are indicated on the map, but there does not seem much hope of working them to profit.

In the mineral veins of Leadhills and Wanlockhead, copper pyrites is occasionally found. Trial mines for copper ore have been opened in the Auchencat Burn, near Hartfell, north of Moffat, and in the island of Hestan on the shores of the Solway, at which latter locality the vein occurs in strata altered by the Criffel granite mass. A thin vein of copper-pyrites was mined at Wauk Mill, near Kirkcowan, in Wigtownshire, where this ore appears in the Llandovery Grits near the northern margin of the Central Belt. Copper-pyrites is likewise found in the vein already referred to at Tonderghie near Whithorn.

Antimony.—On part of the Knipes granite, at a place called Hare Hill, to the south-west of New Cumnock, a vein of antimonite or sulphuret of antimony was formerly worked. Though the mining operations have been discontinued, much of the ore is still to be found at the old workings. Another "antimony mine" occurs in the valley of the Glenshama Burn, which joins the Megget Water—a tributary of the river Esk in Dumfriesshire. Here, on the south slope of the Grey Hill and about a mile E.S.E. of Glendinning Farmhouse, a vein yielding this ore appears in the Hawick Rocks. Its trend is approximately E.N.E. and W.S.W. The "vein stuff" consists of brecciated greywackes and shales, cemented with calcareous matter. In the mineral veins of Leadhills and Wanlockhead small quantities of antimony are also met with.

Manganese.—On the old Sanquhar road, about a mile north-east from Wardlaw Hill, small quantities of finely mammillated pyrolusite occur in a vein of barytes. The same ore appears in the mineral veins of Leadhills.

Zinc.—Sulphuret of zinc ("Black Jack") is of frequent occurrence in the galena veins of Leadhills, Wanlockhead, and Blackcraig near Newton-Stewart.

Mispickel.—Arsenical pyrites is worked in a vein along the junction of the Cairnsmore of Fleet granite mass with the altered Silurian rocks, in the valley of Palnure, north-east of Newton-Stewart.

Silver.—From the galena veins of Leadhills and Wanlockhead silver has been extracted with profit, and small quantities have also been obtained from the lead ore at Blackcraig, near Newton-Stewart.

Gold.—From the alluvial deposits of the streams in the district of Leadhills and Wanlockhead gold has been collected in small quantities for more than three centuries.

Barytes.—In the Upper Silurian (Wenlock) rocks, veins of barytes occur at Barlocco, on the Rerwick shore, Kirkcudbrightshire. Again, in the Upper Silurian rocks of the Lesmahagow district veins of barytes appear, near the head of the river Nethan and its tributary, the Pockmuir Burn, and also in the northern slope of Nutberry Hill.

Mineral Wells.—At various localities in the Southern Uplands mineral wells occur on the lines of outcrop of the black shale series, of which the best known are those in the Moffat

district and at Lawrieston near Castle-Douglas. Indeed, much of the prosperity of Moffat is due to the efficiency of its mineral waters, which still continue to attract a large number of visitors. Here there are two springs, the most powerful one being situated about a mile north-east of the town, the other in Hartfell "score." The following analysis of the water from the Moffat well, made by Mr. Johnstone, Edinburgh, was published in the "Chemical News," 1875, and inserted in Forrest's "Guide to Moffat":

Specific gravity at 60° F., 1001·068.
Temperature. 49·5° F.
Temperature of air, 64·0° F.

Sodium chloride,	0·8524
Sodium sulph-hydrate,	0·0078
Calcium chloride,	0·1243
Calcium sulphate,	0·0125
Calcium carbonate,	0·0940
Magnesic chloride,	0·0581
Magnesic carbonate,	0·0402
Potassic chloride,	0·0616
Ferrous carbonate.	0·0247
Silica.	0·0180
	1·2936
Total residue in one litre dried at 356° F.,	1·3874
Volatile and organic matter,	0·1150
Total solid residue in one litre,	1·5024

Iodine, manganese, and lithia in minute traces.

Gases dissolved in one litre,	34·508 c.c.
Hydrogen sulphide,	5·325
Nitrogen,	25·644
Carbonic dioxide,	2·539
Oxygen,	0·999
	34·507

A sulphureous spring issues from the Silurian rocks at Kirkurd, Peeblesshire, similar to the springs at Moffat.

Chalybeate springs are found in many places throughout the Southern Uplands, more especially along or near the outcrops of the pyritous shales.*

* In the preparation of this chapter the descriptive notes of the economic products already published in the Explanations of the Geological Maps, have been used.

APPENDIX.

I.—LISTS OF FOSSILS FROM THE SILURIAN ROCKS OF THE SOUTH OF SCOTLAND.

The following lists and comparative tables of fossils from the Silurian rocks of the South of Scotland, with the exception of that of the Girvan district, supplied by Mrs. Gray, have been compiled by B. N. Peach, with the assistance of A. Macconochie.

It has now been demonstrated all the world over, wherever Silurian strata have been studied, that graptolites, where they occur, afford the most reliable means of sub-dividing the formation. List No. 1 has therefore been restricted to the graptolites from the South of Scotland collected by the Geological Survey. With the exception of a few species collected by R. Gibbs in the Lammermuirs, and by James Bennie from the Pentland Hills and the Kirkcudbrightshire shores, and some few gathered by the surveyors while working out their several areas, the great bulk of the specimens, amounting to several thousands, have been collected by A. Macconochie. Part of this collection, gathered prior to 1879, was determined by R. Etheridge, jr., acting as Palæontologist to the Scottish branch of the Survey, with the assistance of Professor H. A. Nicholson. From that date, B. N. Peach has acted as Palæontologist, and is mainly responsible for the determinations given in this list. Doubtful cases of identification have from time to time been referred to Professor Lapworth, who has also kindly looked over the Survey Collection displayed in the Edinburgh Museum of Science and Art, and has thus rendered invaluable assistance to the compilers of the list.

List No. 2 comprises all the fossils, with the exception of graptolites, from the Silurian rocks of the Southern Uplands in the collection of the Geological Survey, whether collected directly by the Survey or acquired by presentation or purchase. The greater portion of these fossils has been collected by R. Gibbs, A. Macconochie, James Bennie, some by David Tait, and also by members of the staff.

The early lists were determined by the late J. W. Salter and by R. Etheridge, sen. During his term of office as Acting Palæontologist to the Scottish branch, R. Etheridge, jr., also determined several forms, and subsequently, in conjunction with Professor H. A. Nicholson, named several Survey specimens while preparing their monograph on the Silurian Fossils of Girvan. After the year 1879, B. N. Peach acted as Palæontologist, and is mainly responsible for the list as presented. In

addition to the work of the members of the staff, the assistance of specialists outside the Survey has been freely given. Thus the late Thomas Davidson named the whole collection of Silurian Brachiopods in the possession of the Geological Survey of Scotland a few years prior to his death, and many Survey specimens are figured by him in his monograph. As above mentioned, Professor H. A. Nicholson gave valuable assistance to R. Etheridge, jr., especially with the Silurian Corals and stony Hydrozoa. Dr. G. J. Hinde determined the Radiolarians, and many of the sponges enumerated in the list. The Entomostraca and Phyllocaridea have, for the most part, been through the hands of Professor T. R. Jones and Dr. H. Woodward, several specimens belonging to the latter group being figured in their monograph. The Merostomata in the Jermyn Street Museum, London, have been studied by Dr. H. Woodward, and largely made use of by him for his monograph on that group. Mr. Malcolm Laurie has kindly given his assistance in determining the Merostomata from the Pentland Hills and the Downtonian rocks of the Lesmahagow and Hagshaw Hills. To Dr. R. H. Traquair the Survey is indebted for working out the fish remains.

List No. 3 has been prepared and placed at the disposal of the Geological Survey by Mrs. Gray from the unrivalled collection she has made from the Silurian rocks of the Girvan district.

Lists No. 4 and No. 5 have been compiled from the following sources:

a. Mrs. Gray's list (No. 3).
b. The Geological Survey list (Nos. 1 and 2).
c. Salter and Sedgwick. A Catalogue of the Collection of Cambrian and Silurian Fossils in the Woodwardian Museum of Cambridge. 4to. Cambridge. 1873.
d. Nicholson, H. A., and R. Etheridge, jun. A Monograph of the Silurian Fossils of the Girvan District in Ayrshire. 8vo. Edin. and London. 1880.
e. Davidson, Thos. A Monograph of the British Fossil Brachiopoda. (Palæontograph. Soc.) 4to. London. 1851-1884.
f. Salter, J. W. A Monograph of the British Trilobites (Palæontograph. Soc.) 4to. London. 1864-1883.
g. Lapworth, Prof. Chas. The Girvan Succession. Quart. Jour. Geol. Soc. Vol. xxxviii., p. 537. 1882.
h. Blake, J. F. A Monograph of the British Fossil Cephalopoda. 4to. London. 1882.

List No. 6 has been compiled chiefly from the Geological Survey lists (Nos. 1 and 2), from the papers of Messrs D. J. Brown and J. Henderson on the Upper Silurian Rocks of the Pentland Hills, from Sedgwick's and Salter's Cambridge Catalogue, and from the following sources:

Jones, T. Rupert, and H. Woodward. A Monograph of the British Fossil Phyllopoda. (Palæontograph. Soc.) London. 1888.
Woodward, Dr. H. A Monograph of the British Fossil Crustacea (Merostomata). (Palæontograph. Soc.) 1866-1878.

No. 1. – General List of the Graptolites from the Silurian Rocks of the South of Scotland Collected by the Geological Survey.

	Arenig.	Llandeilo.		Caradoc.		Llandovery.			Wenlock.	Ludlow.
		Lower Llandeilo.	Upper Llandeilo (Glenkiln).	Lower Caradoc (L. Hartfell).	Upper Caradoc (Upper Hartfell).	Lower Birkhill.	Upper Birkhill.	Tarannons, including the Hawick Rocks.		
Tetragraptus (*Salter*)										
,, Bigsbyi (*Hall*) ...	×									
,, bryonoides (*Hall*)	×									
,, fruticosus (*Hall*)	×									
,, Headi (*Hall*) ...	×									
,, quadribrachiatus (*Hall*) ...	×									
,, sp.	×									
Dichograptus (*Salter*)										
,, multiplex (*Nich.*) ...	×									
,, octobrachiatus (*Hall*) ...	×									
,, reticulatus (*Nich.*) ...	×									
,, sp.	×									
Loganograptus (*Hall*)										
,, Logani (*Hall*)			×							
Trigonograptus (*Nicholson*)										
,, ensiformis (*Hall*) ...	×									
Phyllograptus (*Hall*)										
,, typus (*Hall*) ...	×									
Callograptus (*Hall*)										
,, diffusus (*Hall*) ...	×									
,, (?) Salteri (*Hall*)			×							
Dendrograptus (*Hall*)										
,, gracilis (*Hall*)			×							
,, sp.			×							
Didymograptus (*M'Coy*)										
,, extensus (*Hall*) ...	×		(?)							
,, patulus (*Hall*)	×									
,, serratulus (*Hall*) ...			×							
,, superstes (*Lapw.*) ...			×							
Cœnograptus (*Hall*)										
,, gracilis (*Hall*)...			×							
,, nitidulus (*Lapw.*) ...			×							

	Arenig.	Llandeilo.		Caradoc.		Llandovery.			Wenlock.	Ludlow.
		Lower Llandeilo.	Upper Llandeilo (Glenkiln).	Lower Caradoc (L. Hartfell).	Upper Caradoc (Upper Hartfell).	Lower Birkhill.	Upper Birkhill.	Tarannons, including the Hawick Rocks.		
Cœnograptus pertenuis (*Lapw.*) ...			×							
,, surcularis (*Hall*)			×							
Leptograptus (*Lapworth*)										
,, capillaris (*Carr.*)				×						
,, flaccidus (*Hall*)			×	×						
Amphigraptus (*Lapworth*)										
,, divergens (*Hall*)				×						
,, radiatus (*Lapw.*) ...				×						
Pleurograptus (*Nicholson*)										
,, linearis (*Carr.*)				×						
Dicellograptus (*Hopkinson*)										
,, anceps (*Nich.*)					×					
,, caduceus (*Lapw.*) ...				×						
,, complanatus (*Lapw.*) ...					×					
,, divaricatus (*Hall*) ...			×							
,, elegans (*Carr.*)				×						
,, flexuosus (*Lapw.*) ...			×							
,, Forchhammeri (*Geinitz*) ...				×						
,, intortus (*Lapw.*) ...			×							
,, moffatensis (*Carr.*) ...			×	×						
,, Morrisi (*Hopk.*)				×						
,, patulosus (*Lapw.*) ...			×							
,, pumilus (*Lapw.*) ...				×						
,, sextans (*Hall*)			×							
Dicranograptus (*Hall*)										
,, Clingani (*Carr.*) ...				×						
,, formosus (*Hopk.*) ...			×							
,, Nicholsoni (*Hopk.*) ...			×	×						
,, ramosus (*Hall*)			×	×						
,, rectus (*Hopk.*)			×							
,, tardiusculus (*Lapw.*) ...			×							
,, zic-zac (*Lapw.*)			×							
,, minimus (*Lapw.*)			×							
,, nov. sp. ...			×							
Climacograptus (*Hall*)										
,, bicornis (*Hall*)			×	×	×					
,, caudatus (*Lapw.*) ...				×						

	Arenig.	Llandeilo.		Caradoc.		Llandovery.			Wenlock.	Ludlow.
		Lower Llandeilo.	Upper Llandeilo (Glenkiln).	Lower Caradoc (L. Hartfell).	Upper Caradoc (Upper Hartfell).	Lower Birkhill.	Upper Birkhill.	Tarannons, including the Hawick Rocks.		
Climacograptus cœlatus (*Lapw.*) ...			×							
,, cœlatus, var. antiquus (*Lapw.*) ...			×							
,, confertus (*Lapw.*) ...	×									
,, innotatus (*Nich.*) ...						×				
,, normalis (*Lapw.*) ...						×	×	×		
,, peltifer (*Lapw.*) ...			×							
,, rectangularis (*M'Coy*) ...						×				
,, Schärenbergi (*Lapw.*) ...			×	×						
,, styloideus (*Lapw.*) ...				×						
,, tridentatus (*Lapw.*) ...			×	×						
,, tubuliferus (*Lapw.*) ...				×	×					
,, Wilsoni (*Lapw.*) ...				×						
,, nov. sp. ...					×	×				
Diplograptus (*M'Coy*) aculeatus (*Lapw.*) ...				×						
,, acuminatus (*Nich.*) ...						×				
,, angustifolius (*Hall*) ...			×							
,, (Dimorphograptus) confertus (*Nich.*) ...						×				
,, euglyphus (*Lapw.*) ...			×							
,, foliaceus (*Murch.*) ...			×	×	×					
,, Hughesi (*Nich.*)						×	×			
,, mucronatus (*Hall*) ...			×							
,, perexcavatus (*Lapw.*) ...			×	×						
,, physophora (*Nich.*) ...						×				
,, quadrimucronatus (*Hall*) ...				×						
,, rugosus (*Emm.*)				×						
,, sinuatus (*Nich.*)							×	×		
,, socialis (*Lapw.*)					×					
,, tamariscus (*Nich.*) ...						×	×	×		

	Arenig.	Llandeilo. Lower Llandeilo.	Llandeilo. Upper Llandeilo (Glenkiln).	Caradoc. Lower Caradoc (L. Hartfell).	Caradoc. Upper Caradoc (Upper Hartfell).	Llandovery. Lower Birkhill.	Llandovery. Upper Birkhill.	Llandovery. Tarannous, including the Hawick Rocks.	Wenlock.	Ludlow.
Diplograptus truncatus (*Lapw.*) ...					×	•				
,, vesiculosus (*Nich.*) ...						×				
,, Whitfieldi (*Hall*)			×							
Dimorphograptus (*Lapworth*)										
,, elongatus (*Lapw.*)...						×				
,, Swanstoni (*Lapw.*)...						×				
Petalograptus (*Suess*)										
,, folium (*His.*) ...						×	×			
,, ovatus (*Barr.*)								×		
,, palmæus (*Barr.*)							×	×		
,, ,, var. latus (*Barr.*)						×				
,, ,, var. ovato-elongatus (*Kurck.*)						×	×	×		
Cephalograptus (*Hopkinson*)										
,, cometa (*Geinitz*) ...							×			
Cryptograptus (*Lapworth*)										
,, tricornis (*Carr.*)			×	×						
Lasiograptus (*Lapworth*)										
,, bimucronatus (*Nich.*) ...			×							
,, Harknessi (*Nich.*) ...			×	×						
,, margaritatus (*Lapw.*) ...				×						
Glossograptus (*Emmons*)										
,, Hincksi (*Hopk.*)			×	×						
Retiolites (*Barrande*)										
,, (Neurograptus) fibratus (*Lapw.*)...				×						
,, geinitzianus (*Barr.*)		•						×	×	
,, perlatus (*Nich.*) ...							×			
,, ,, var. Daironi (*Lapw.*)							×			
,, sp.				×						
Clathrograptus (*Lapworth*)										
,, cuneiformis (*Lapw.*) ...			×							
Monograptus (*Geinitz*)										
,, argutus (*Lapw.*)							×			
,, attenuatus (*Hopk.*) ...						×	×	×		
,, Barrandei (*Tullb.*)								×		
,, Becki (*Barr.*) ...							×	×		
,, Clingani (*Carr.*)							×			

		Arenig.	Llandeilo.		Caradoc.		Llandovery.			Wenlock.	Ludlow.
			Lower Llandeilo.	Upper Llandeilo (Glenkiln).	Lower Caradoc (L. Hartfell).	Upper Caradoc (Upper Hartfell).	Lower Birkhill.	Upper Birkhill.	Tarannons, including the Hawick Rocks.		
Monograptus	colonus (*Barr.*)									×	
,,	communis (*Lapw.*) ..						×				
,,	concinnus (*Lapw.*) ...							×			
,,	convolutus (*His.*) ...								×		
,,	crenularis (*Lapw.*) ...						×	×			
,,	crispus (*Lapw.*)								×		
,,	cyphus (*Lapw.*)						×	×			
,,	exiguus (*Nich.*)								×		
,,	fimbriatus (*Nich.*) ...						×				
,,	Flemingi (*Salter*)									×	
,,	galaensis (*Lapw.*) ...								×	×	
,,	gregarius (*Lapw.*) ...						×				
,,	Halli (?) (*Barr.*)								(?)		
,,	Hisingeri (*Carr.*)							×	×		
,,	intermedius (*Carr.*) ...							×			
,,	jaculum (*Carr.*)							×			
,,	leptotheca (*Lapw.*) ...						×	×	×		
,,	lobiferus (*M'Coy*) ...						×	×	×		
,,	ludensis (*Murch.*) = (? priodon (*Bronn.*) ...									×	
,,	pandus (*Lapw.*)								×		
,,	priodon (*Bronn.*)								×	×	
,,	proteus (*Barr.*)								×		
,,	riccartonensis (*Lapw.*) ...									×	
,,	runcinatus (*Lapw.*) ...							×	×		
,,	Sandersoni (*Lapw.*) ...						×				
,,	Sedgwicki (*Portl.*) ...							×	×		
,,	spinigerus (*Nich.*) ...							×	×		
,,	(Cyrtograptus?) spiralis (*Geinitz*) ...						×	×	×		
,,	tenuis (*Portl.*)...						×	×	×		
,,	triangulatus (*Hark.*) ...						×				
,,	turriculatus (*Barr.*) ...								×		
,,	vomerinus (*Nich.*) ...								×	×	

	Arenig.	Llandeilo.		Caradoc.		Llandovery.			Wenlock.	Ludlow.
		Lower Llandeilo.	Upper Llandeilo (Glenkiln).	Lower Caradoc (L. Hartfell).	Upper Caradoc (Upper Hartfell).	Lower Birkhill.	Upper Birkhill,	Tarannone, including the Hawick Rocks.		
Rastrites (*Barrande*)										
,, capillaris (*Carr.*) ...							×			
,, distans (*Lapw.*) ...							×			
,, hybridus (*Lapw.*) ...							×			
,, maximus (*Carr.*) ...							×	×		
,, peregrinus (*Barr.*)...						×	×			
Cyrtograptus (*Carruthers*)										
,, Carruthersi (*Lapw.*) ...									×	
,, Grayi (*Lapw.*)								×		
,, Murchisoni (*Carr.*) ...									×	
Buthograptus (*Hall*)										
,, laxus (*Hall*) ...				×						
,, sp.				×						
Corynoides (*Nicholson*)										
,, calycularis (*Nich.*)			×	×						
,, curtus (*Lapw.*) ...				×						
,, nov. sp.				×						
Dawsonia (*Nicholson*)										
,, campanulata (*Nich.*)						×	×			
Dictyonema (*Hall*)										
,, delicatulum (*Lapw.*) ...								×		
,, irregulare ? (*Hall*)								×		
,, moffatense (*Lapw.*)				×						
,, retiforme (*Hall*)...				×						
,, sociale (*Salt.*) ...						×				
,, venustum (*Lapw.*)								×		
Thamnograptus (*Hall*)										
,, typus (*Hall*)			×							
,, scoticus (*Lapw.*) ...			×							
Ptilograptus (*Hall*)										
,, sp.						×				

No. 2.—General List of Fossils, Exclusive of Graptolites, from the Silurian Rocks of the South of Scotland, in the Collections of the Geological Survey.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
Plantæ.						
Chondrites (*Sternberg*)						
,, verisimilis (*Salt.*)				×	×	8, 32 (?).
,, sp.					×	32.
Girvanella (*Nicholson and Etheridge*)						
,, problematica (*N. and E.*)		×				8, 32.
Land plants (?)...					×	10, 11, 17, 32.
Pachytheca sp....					×	23.
Rhizopoda ?						
Cyclocrinus (*Eichwald*)						
,, sp.			×			15.
Nidulites (*Salter*)						
,, favus (*Salt.*) ...		×	×	×		8, 14, 15, 24.
Foraminifera.						
Saccammina (*Sars*)						
,, Carteri (*Brady*)...		×				7, 8.
Radiolaria.						
Styptosphæra (*Hœckel*)						
,, antiqua (*Hinde*)	×	×				
Spongoplegma (*Hœckel*)						
,, priscum (*Hinde*)	×	×				
Diploplegma (*Hinde*)						
,, cinctum (*Hinde*)	×	×				
Staurodorus (*Hœckel*)						
,, gracilis (*Hinde*)...	×	×				
Stauroplegma (*Hinde*)						
,, brevispina (*Hinde*) ...	×	×				
,, compressum (*Hinde*) ...	×	×				
,, barbatum (*Hinde*) ...	×	×				
,, diffusum (*Hinde*) ...	×	×				
Acanthosphæra (*Ehrenberg*)						
,, antiqua (*Hinde*) ...	×	×				

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
RADIOLARIA—*continued.*						
Haliomma (*Ehrenberg*)						
,, cornutum (*Hinde*)	×	×				
,, vetustum (*Hinde*)	×	×				
Dorysphæra (*Hinde*)						
,, laxa (*Hinde*) ...	×	×				
,, reticulata (*Hinde*)	×	×				
Doryplegma (*Hinde*)						
,, gracile (*Hinde*) ...	×	×				
,, nasutum (*Hinde*) ...	×	×				
Dorydictyum (*Hinde*)						
,, simplex (*Hinde*)	×	×				
Triposphæra (*Hinde*)						
,, armata (*Hinde*)	×	×				
,, densa (*Hinde*) ...	×	×				
,, hastata (*Hinde*)	×	×				
,, Peachi (*Hinde*) ...	×	×				
Sphærozoum (*Meyen*)						
,, patulum (*Hinde*)	×	×				
,, priscum (*Hinde*)	×	×				
SPONGIDA.						
Amphispongia (*Salter*)						
,, oblonga (*Salt.*)					×	32.
Hyalostelia (*Zittel*)						
,, (Hyalonema) fasciculus (*M'Coy*) ...	×	×	×			8, 15, 16, 24.
,, sp.	×					7.
Ischadites (*Murchison*)						8.
,, antiquus (*Salt.*) ...				×		8.
,, Kœnigi (*Murch.*) ...				×		8, 32.
,, sp.			×			
Protospongia (*Salter*)						
,, sp.					×	10.
Sponge, ...	×	×			×	3, 7, 8, 15, 32, 33.
ACTINOZOA.						
Alveolites (*Lamarck*)						
,, repens (*Fougt.*) . .					×	32.
,, sp.			×		×	15, 32.
Aulacophyllum (*Edwards and Haime*)						
,, mitratum (*His.*)				×		14.
Calostylis (*Lindström*)						
,, Lindströmi (*N. and Eth.*) ...				×		8.
Chætetes (*Fischer*)						
,, sp.				×		14.
Favosites (*Lamarck*)						
,, alveolaris (*Goldf.*)					×	32.
,, asper (?) *D'Orb.*) ...			×	×		14, 15.
,, cristatus (*Blum.*) ...			×			24.
,, gothlandicus (*Fougt.*) ...			×	×	×	3, 11, 14, 24, 32.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
ACTINOZOA—*continued.*						
Favosites mullochensis (*N. and Eth.*)...				×		7, 14.
,, sp.			×	×	×	
Halysites (*Fischer*)						
,, catenulatus (*Linn.*)				×		8.
Heliolites (*Dana*)						
,, interstinctus (*Linn.*)				×		14, 32.
,, parasiticus (*N. and Eth.*) ...				×		14.
,, tubulatus, (*Lonsd.*)				×		14.
,, sp.			×	×	×	2, 4, 5, 10, 11, 14, 32.
Lindströmia (*Nicholson and Thomson*)						
,, (Petraia) subduplicata (*M'Coy*) ...			×	×		14, 15, 24.
,, ,, var. crenulata (*M'Coy*) ...				×		14, 24.
Lyopora (*Nicholson and Etheridge*)						
,, favosa (*M'Coy*) ...		×	×			14, 24.
Monticulipora (*D'Orbigny*)						
,, lens (*M'Coy*) ...			×			15.
Palæocyclus (*Edwards and Haime*)						
,, sp.			×	×		14, 15, 24, 25.
Petraia (*Münster*)						
,, bina (*Lonsd.*)			×	×	×	5, 8, 14, 15, 24, 25.
,, elongata (*Phil.*) ...		×	×	×	×	5, 14, 15.
,, uniserialis (*M'Coy*) ...			×			15, 24.
,, zic-zac (*M'Coy*) ...			×			15.
,, sp.			×	×	×	4, 8, 32.
Pinacopora (*Nicholson and Etheridge*)						
,, Andersoni (*N. and Eth*) ...				×		7.
,, Grayi (*N. and Eth*) ...				×		14.
Prasopora (*Nicholson and Etheridge*)						
,, Grayæ (*N. and Eth.*)		×				14.
Stenopora (*Lonsdale*)						
,, (Favosites) fibrosa (*Goldf.*) ...		×	×		×	5, 14, 15, 24, 32.
Streptelasma (*Hall*)						
,, æquisulcatum (*M'Coy*) ...		×		×		14.
,, craigense (*M'Coy*)		×				14.
Syringophyllum (*Edwards and Haime*)						
,, (Sarcinula) sp.			×			15.
Syringopora (*Goldfuss*)						
,, sp.					×	5.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
ACTINOZOA—*continued.*						
Tetradium (*Dana*)						
,, Peachi (*N. and Eth.*) ...		×				7.
,, sp.			×			15, 32.
OPHIUROIDEA.						
Protaster (*Forbes*)						
,, Sedgwicki (*Forbes*)					×	32.
CYSTOIDEA.						
Echinosphærites (*Wahlenberg*)						
,, (Sphæronites) granulatus (*M'Coy*)			×			8.
CRINOIDEA.						
Glyptocrinus (*Hall*)						
,, basalis (*M'Coy*)			×	×	×	4, 11, 14, 15, 24.
Periechocrinus (*Austen*) ...						
,, moniliformis (*Mill.*) ...					×	32.
,, sp.					×	32.
Crinoid stems.			×	×	×	2, 4, 5, 8, 11, 14, 24, 25, 32.
ANNELIDA.						
Arabellites (*Hinde*)						
,, sp.	×					15, 24.
Cornulites (*Schlotheim*)						
,, serpularis (*Sch.*) ...			×			15.
,, sp.					×	5, 14, 32.
Serpulites (*M'Leay*)						
,, longissimus (*Murch.*)		×	×		×	8, 14, 15, 32.
,, sp.		×			×	15, 32.
Spirorbis (*Lamarck*)						
,, Lewisi (*Sow.*) ...					×	17, 23, 32.
Tentaculites (*Schlotheim*)						
,, anglicus (*Salt.*)...				×		14.
,, ornatus (*Sow.*) ...		×				8.
CIRRIPEDIA.						
Turrilepas (*Woodward*)						
,, Peachi (*N. and Eth.*)			×			7.
,, scotica (*N. and Eth.*)			×			7.
,, Wrighti (*Woodw.*)					×	32.
,, sp.		×	×		×	8, 24, 32.
OSTRACODA.						
Beyrichia (*M'Coy*)						
,, impendens (*Jones*)					×	8, 14, 32.
,, Klædeni (*M'Coy*)...				×	×	8, 14, 23, 32.
,, ,, var. torosa (*Jones*)					×	23.
Cythere (Cytheropsis) (*Müller*)						
,, aldensis (*M'Coy*) ...			×			7.
Entomis (*Jones*)						
,, globulosa (*Jones*) ...					×	8.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
OSTRACODA—*continued.*						
Entomis sp.					×	32.
Primitia (*Jones and Holl*)						
,, sp.					×	14.
PHYLLOCARIDA.						
Aptychopsis (*Barrande*)						
,, angulata (*Baily*)				×		9.
,, barrandiana (*Jones and Woodw.*) ..				×		16.
,, glabra (*Woodw.*)				×		25.
,, Lapworthi (*Woodw.*)...				×		16.
,, lata (*Jones*) ..					×	17.
,, minor (*Barr.*) ...				×		5.
,, oblata (*Jones*) ...					×	5, 17.
,, ovata (*Jones*) ...				×	×	2, 17.
,, Wilsoni (*Woodw.*)					×	10, 17.
,, sp.					×	2.
Ceratiocaris (*M'Coy*)						
,, inequalis (*Barr.*)					×	10.
,, inornatus (*M'Coy*)					×	23.
,, laxa (*Jones and Woodw.*) ...					×	23.
,, leptodactylus (*M'Coy*) ...					×	24, 32.
,, longa (*Jones and Woodw.*) ...					×	23.
,, ludensis (*Woodw.*)					×	17.
,, Murchisoni (*M'Coy*) ...					×	24, 32.
,, papilio (*Salter*) ...					×	10, 15, 17, 23.
,, stygius (*Salt.*) ...					×	15, 23.
,, tyrannus (*Salt.*)					×	10.
,, sp.				×	×	5, 10, 17, 24, 25, 32.
Discinocaris (*Woodward*)						
,, browniana (*Woodw.*)..				×		1, 5, 9, 10, 16, 25.
,, gigas. (*Woodw.*)				×		10.
,, sp.					×	5, 10, 17.
Dithyrocaris (*Scouler*)						
,, striata (*Eth., jnr.*)					×	23.
Peltocaris (*Salter*)						
,, anatina (*Salt.*) ...				×		9.
,, aptychoides (*Salt.*)				×		1, 9, 10, 16, 25.
,, sp.			×	×	×	2, 4, 8.
Pinnocaris (*Etheridge, jnr.*)						
,, Lapworthi (*Eth., jnr.*)			×			8.
Caryocaris (*Salter*)						
,, Wrighti (*Salt.*) ...	×					7, 15.
TRILOBITA.						
Acidaspis (*Murchison*)						
,, Grayæ (*Eth., jnr.*)...			×			8.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
TRILOBITA—*continued.*						
Acidaspis hystrix (*Wyv.-Thom.*) ...			×			8.
,, sp.				×	×	8, 14, 32.
Agnostus (*Brongniart*)						
,, agnostiformis (*M'Coy*) ...			×			8.
,, perrugatus (*Barr.*)			×			7.
Ampyx (*Dalman*)						
,, Hornei (*Eth. and N.*)			×			8.
,, Maccallumi (*Salt.*) ...			×			7, 8.
,, mammillatus (*Sars.*)...			×			8.
,, nasutus (*Dalm.*) ...			×			8.
,, nudus (*Murch.*) ...			×			8.
,, rostratus (*Sars.*) ..			×			8, 14.
,, sp.		×				8.
Asaphus (*Brongniart*)						
,, (Isotelus) gigas (*Dekay*)			×			7, 8.
,, ,, rectifrons (*Portl.*) ...		×	(?)			7.
,, sp.			×			8, 24.
Barrandia (*M'Coy*)						
,, sp.			×			8.
Bronteopsis (*Wyv. - Thomson*)						
,, scotica (*Salter*) ...			×			8.
Bronteus (*Goldfuss*)						
,, Andersoni (*Eth. and N.*) ...			×	×		7, 8.
,, hibernicus (*Portl.*)			(?)			7, 8.
Calymene (*Brongniart*)						
,, Blumenbachi (*Brong.*) ...		×	×	×	×	7, 8, 14.
,, tuberculosa (*Salt.*)...			×			14.
,, sp.			×		×	7, 15, 32.
Cheirurus (*Beyrich*)						
,, bimucronatus (*Murch.*)...		×	×	×		7, 8, 14, 24.
,, clavifrons (*Dalm.*)...			×			14, 24.
,, gelasinosus (*Portl.*)			×			8, 24.
,, trispinosus (*Young*)				×		8.
,, sp.			×	×		8, 15, 24.
Cybele (*Lovén*)						
,, rugosa (*Portl.*) ...			×			8, 14.
,, verrucosa (*Dalm.*) ...			×			8.
Cyclopyge (*Hawle and Corda*)						
,, armata (*Barr.*) ...			×			7.
,, rediviva (*Barr.*) ...			×			7.
Dindymene (*Corda*)						
,, Cordai (*Eth. and N.*) ...			×			14.
Dionide (*Barrande*)						
,, Lapworthi (*Eth. and N.*) ...			×			7, 14 (?).
,, sp.			×			7, 14.
Encrinurus (*Emmrich*)						
,, punctatus (*Brün.*)		×	×	×	×	7, 8, 14, 32.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
TRILOBITA—*continued.*						
Eucrinurus punctatus, var. arenaceus (*Salt.*)		×		×	×	8, 14.
,, ,, var. calcareus (*Salt.*)				×		7.
,, sp.					×	32.
Harpes (*Goldfuss*)						
,, sp.		×	×			7, 8.
Homalonotus (*Kœnig*)						
,, sp.			×			15.
Illænus (*Dalman*)						
,, (Dysplanus) æmulus (*Salt.*) ...				×		8.
,, ,, Thomsoni (*Salt.*) ...			×	×		8, 14.
,, (Bumastus) Barriensis (*Murch.*) ...				×		8.
,, ,, Bowmani (*Salt.*)		×	×	×		7, 8, 14, 21.
,, ,, Macallumi (*Salt.*) ...				×		14.
,, Davisi (*Salt.*) ...			×			24.
,, var. B. involutus (*Salt.*)			×			24.
,, latus (?) (*M'Coy*) ...		×	×			8, 15.
,, nexilis (*Salt.*)... ...			×	×		14.
,, sp.		×	×	×		
Lichas (*Dalman*)						
,, Barrandei (*Flet.*) ...				×		14.
,, Geikiei (*Eth. and N.*)			×			14.
,, hibernicus (*Portl.*) ...		×	×			8, 14.
Ogygia (*Brongniart*)						
,, sp.			×			15.
Phacops (*Emmrich*)						
,, (Acaste) alifrons (*Salt.*) ...			×			24.
,, ,, Brongniarti (*Portl.*)		×	×			7, 8, 14, 15, 24.
,, ,, Downingiæ (*Murch.*)				×	×	7, 14, 32.
,, (Dalmanites) caudatus (*Brün.*) ...			(?)			5, 15, 24.
,, Dalmani (*Portl.*) ...			×			7.
,, Macconochiei (*Eth. and N.*) ...			×			9.
,, Stokesi (*M. Edw.*) ...					×	14.
,, sp.			×	×	×	8, 14, 25, 32.
Proetus (*Steininger*)						
,, girvanensis (*E. and N.*)			×	(?)		8, 14.
,, latifrons (*M'Coy*) ...			×			14.
,, procerus (*E. and N.*)			×			14.
,, Stokesi (*Murch.*) ...					×	14.
,, sp.				×		8.
Remopleurides (*Portlock*)						
,, Barrandei (*Eth. and N.*) ...		×	×			7, 8.

	Arenig.	Llandeilo.	Caradoc.	Llandovery	Wenlock-Ludlow.	One-inch Maps.
TRILOBITA—*continued.*						
Remopleurides Colbii (*Portl.*)		×	×			7, 8, 15.
,, laterispinifer (*Portl.*) ...		×	×			7, 8, 15.
,, nov. sp. ...			×			15.
,, sp.		×	×			7.
Salteria (*Wyv.-Thomson*)						
,, primæva (*Wyv.-Thom.*)			×			8.
Sphærexochus (*Beyrich*)						
,, mirus (*Beyr.*)...			×			24.
Staurocephalus (*Barrande*)						
,, globiceps (*Portl.*) ...			×			7, 8, 14.
,, unicus (*Wyv.-Thom.*) ...			×	×		7, 8.
Stygina (*Salter*)						
,, latifrons (*Portl.*) ...			×			7.
Trinucleus (*Lhwyd*)						
,, (?) Benniei (*Eth., jnr.*)					×	5.
,, Bucklandi (*Barr.*)			×			14.
,, concentricus (*Eaton*) ...			×			7.
,, fimbriatus (*Murch.*)...			×			15.
,, Macconochiei (*Eth. and N.*)			×			8.
,, ornatus (*Stern.*) ...			×			8.
,, seticornis (*His.*) ...			×			14.
,, sp.			×			7, 8, 14, 24.
XIPHOSURA.						
Neolimulus (*Woodward*)						
,, falcatus (*Woodw.*)					×	23.
,, sp.					×	23.
EURYPTERIDA.						
Drepanopterus (*Laurie*)						
,, pentlandicus (*Laurie*) ...					×	32.
Eurypterus (*Dekay*)						
,, lanceolatus (*Salt.*)					×	23.
,, punctatus(?) (*Salt.*) ...					×	17.
,, scorpioides (*Woodw.*)...					×	23.
,, sp.				×	×	11, 14, 23, 25.
Pterygotus (*Agassiz*)						
,, bilobus (*Salt.*) ...					×	23, 32.
,, sp....					×	23.
Slimonia (*Page*)						
,, acuminata (*Salt.*) ...					×	23, 32.
Stylonurus (*Page*)						
,, Logani (*Woodw.*)					×	23.
,, ornatus (*Laurie*)...					×	23, 32.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
Polyzoa.						
Ceriopora (*Goldfuss*)						
,, granulosa (*Goldf.*)					×	32.
,, oculata (*Goldf.*) ...			×			24.
,, sp.					×	32.
Diastopora (*Lamouroux*)						
,, sp.					×	32.
Fenestella (*Lonsdale*)						
,, sp.			×	×		7. 14, 15.
Ptilodictya (*Lonsdale*)						
,, costellata (*M'Coy*)			×	×		14, 24.
,, dichotoma (*Portl.*)			×			8, 15.
,, lanceolata (*Goldf.*)					×	14.
,, sp....			×	×	×	4, 5, 8, 14, 25, 32.
Sulcoretepora (*D'Orbigny*)						
,, sp.			×			15.
Brachiopoda.						
Acrothele (*Linnarsson*)						
,, granulata (*Linnr.*)	×	×				3, 4, 5, 7, 8, 9, 15, 16, 24.
,, sp.	×					15.
Acrotreta (*Kutorga*)						
,, Nicholsoni (*Dav.*)	×	×	×			3, 7, 8, 9, 10, 14, 15, 16, 24.
,, sp.	×	×				7, 15.
Athyris (*M'Coy*)						
,, (Glassia) compressa (*Sow.*) ...					×	32.
,, sp.					×	5.
Atrypa (*Dalman*)						
,, (Leptocœlia) hemispherica (*Sow.*) ...			×	×	×	5, 8, 14.
,, imbricata (*Sow.*) ...				×		7.
,, marginalis (*Dalm.*) ...			×			8.
,, reticularis (*Linn.*) ...			×	×	×	7, 8, 14, 32.
,, scotica (*M'Coy*) ...			×			8.
Chonetes (*Fischer*)						
,, striatella (*Dalm.*) ...					×	32.
,, sp.					×	32.
Crania (*Retzius*)						
,, (Pholidops) implicata (*Sow.*) ...					×	32.
,, siluriana (*Dav.*) ...		×		×		7, 14.
,, sp.				×		14.
Cyrtia (*Dalman*)						
,, exporrecta (*Wahl.*) ...				×	×	8, 32.
Discina (*Lamarck*)						
,, oblongata (*Portl.*) ...			×			7, 8, 14, 16.
,, perrugata (*M'Coy*) ...		×	×	×		8. 14, 24.
,, Portlocki (*Geinitz*) ...		×				4, 15, 24, 33.
,, rugata (*Sow.*)... ...		×	×	×		7, 8, 14, 24.
,, sp.	×	×	×	×		3, 7, 10, 15, 16, 24.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
BRACHIOPODA—*continued.*						
Glassia (*Davidson*)						
,, (Athyris) obovata (*Sow.*)				×		8.
Kutorgina (*Billings*)						
,, Labradorica (*Bill.*)	×					15.
,, sp.	×					7, 15, 24.
Leptæna (*Dalman*)						
,, Etheridgei (*Dav.*) ...		×				14.
,, (Plectambonites) quinque costata (*M'Coy*)		×	×	×		7, 8, 24.
,, scissa (*Salt.*) ...			×			7, 8, 24.
,, segmentum (*Angelin*)				×		7.
,, sericea (*Sow.*) ...		×	×	×	×	5, 7, 8, 14, 15, 24, 25, 32.
,, ,, var. rhombica (*M'Coy*)		×	×			8, 14, 15.
,, (Christiania) tenuicincta (*M'Coy*) ...		×	×	×		7, 8, 14, 15, 24.
,, (Plectambonites) transversalis (*Wahl.*) ...		×	×	×	×	5, 7, 8, 14, 15, 24, 32.
,, var.				×		7.
,, youngiana (*Dav.*) ...		×				14.
,, sp.			×			24.
Lingula (*Bruguière*)						
,, attenuata (*Sow.*) ...			×			7, 8, 14, 15, 24.
,, brevis (*Portl.*) ..			×	×		7, 8, 15.
,, crumena (*Phill.*) ...			×			8.
,, lata (*Sow.*)					×	32.
,, Lewisi (*Sow.*) ...					×	32.
,, longissima (*Pand.*) ...			×			24.
,, minima (*Sow.*) ...					×	23.
,, ovata (*M'Coy*) ...		×	×			8, 14.
,, quadrata (*Eichw.*) ...		×				14.
,, Ramsayi (*Salt.*) ...		×	×			8, 14, 24.
,, striata (*Sow.*) ...				×		5.
,, Symondsi (*Salt.*) ...				×	×	7, 8, 14.
,, sp.	×	×	×	×	×	3, 7, 10, 14, 15, 32.
Lingulella (*Salter*)						
,, Davisii (?) (*M'Coy*)		×				8.
,, lepis (*Salt.*) ...	×	×				7, 15.
,, quebeccensis (*Bill.*)	×					15.
,, sp.	×					15.
Linnarssonia (*Walcot*)						
,, (Obolella) sagittalis (*Salt.*)	×	×				7, 15, 24.
,, sp.	×					15.
Merista (*Hall*)						
,, cymbula (*Dav.*) ...			×			14.
Meristella (*Hall*)						
,, angustifrons (*M'Coy*)				×		14.
,, MacLareni (*Hasw.*)					×	32.
,, (Whitfieldia) tumida (*Dalm.*) ...			×		×	24, 32.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
BRACHIOPODA—*continued.*						
Nucleospira (*Hall*)						
,, pisum (*Sow.*) ...		?			×	7, 32.
,, sp.					×	32.
Obolella (*Billings*)						
,, Sabrinæ (*Callaw.*) ...	×					15.
,, sp.	×	×				7, 15, 24.
Orbiculoidea (*D'Orbigny*)						
,, Forbesi (*Dav.*) ...				×	×	7, 32.
Orthis (*Dalman*)						
,, Actoniæ (*Sow.*) ...			×			24.
,, alternata (*Sow.*) ...			×			8.
,, (Platystrophia) biforata (*Schl.*) ...		×	×		×	8, 14, 15.
,, (Bilobites) biloba (*Linn.*)			×	×	×	7, 8, 24, 32.
,, Bouchardi (*Dav.*) ...					×	5, 14.
,, ,, var. Balcletchiensis (*Dav.*) ...		×	×			7, 8, 14.
,, calligramma (*Dalm.*) ...		×	×	×	×	5, 7, 8, 14, 15, 24.
,, ,, var. plicata (*Sow.*)				×		7.
,, ,, var. virgata (*Sow.*)			×			7.
,, confinis (*Salt.*) ...		×	?	?		7, 8, 14.
,, crispa (*M'Coy*) ...		×	×			8, 15, 24.
,, (Dalmanella) elegantula (*Dalm.*)		×	×	×	×	7, 8, 14, 15, 32.
,, (Dinorthis) flabellulum (*Sow.*) ...		×	×		×	8, 10, 14, 24.
,, girvanensis (*Dav.*) ...		×	×			8, 14, 24 (?).
,, intercostata (*Portl.*) ...			×			8.
,, (Strophomena) kilbuchoensis (*Dav.*) ...			×			15, 24.
,, (Skenidium) Lewisi (*Dav.*) ...					×	32.
,, mullockiensis (*Dav.*) ...				×		14.
,, nina (*Dav.*)			×			7.
,, polygramma (*Sow.*) ...				×	×	8, 32.
,, ,, var. pentlandica (*Dav.*) ...			×			15.
,, protensa (*Sow.*) ...			×			15, 24.
,, Rankini (*Dav.*) ...			×			7.
,, reversa (*Salt.*)				×	×	10, 14, 32.
,, rustica (*Sow.*)			×	×	×	7, 14, 24.
,, ,, var. rigida (*Dav.*)			×	×		7, 14.
,, sagittifera (*M'Coy*) ...				×		14.
,, sowerbyana (*Dav.*) ...		×	×			8, 14, 24.
,, (Dalmanella) testudinaria (*Dalm.*)		×	×			7, 14, 15.
,, tricenaria (*Conr.*) ...			×			8.
,, unguis (*Sow.*)			×			24.
,, vespertilio (*Sow.*) ...		×	×			8, 14, 15, 24.
,, sp.		×	×		×	5, 7, 14, 24, 25 (?), 32.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
BRACHIOPODA—*continued.*						
Paterula (*Davidson*)						
,, (Discina) Balcletchiensis (*Dav.*)			×			8.
Pentamerus (*Sowerby*)						
,, globosus (*Sow.*) ...				×		8.
,, oblongus (*Sow.*)...				×		8.
,, ,, var. lævis (?) (*Sow.*) ...				×		8.
,, rotundus (*Sow.*)...				×		8.
,, undatus (*Sow.*) ...				×		7, 8, 14.
,, sp.				×		14.
Porambonites (*Pander*)						
,, intercedens (*Pand.*) ...			×			7, 24.
Retzia (*King.*)						
,, Barrandei (*Dav.*) ...					×	14.
,, sp.			?	×		14.
Rhynchonella (*Fischer*)						
,, æmula (*Salt.*)...		×				14.
,, balcletchiensis (*Dav.*) ...		×				8.
,, borealis(?)(*Schl.*)			?			15.
,, cuneata (*Dalm.*)			×	×		7, 14.
,, ,, var. ardmillanensis (*Dav.*)			×			7.
,, Jacki (*Dav.*) ...			×			15.
,, Lapworthi(*Dav.*)		×				14.
,, llandoveriana (*Dav.*) ...				×		8, 14.
,, maccoyana (*Dav.*) ...			×			24.
,, nasuta (*M'Coy*)		×	×			8, 14.
,, nucula (*Sow.*)...			×		×	8, 32.
,, Peachi (*Dav.*)...		×				14.
,, pentlandica (*Hasw.*) ...					×	32.
,, (Hyattella) portlockiana (*Dav.*) ...		×				14.
,, Salteri (*Dav.*)...			×			8.
,, Stricklandi (*Sow.*) ...			×			15.
,, Thomsoni(*Dav.*)		×				14.
,, Weaveri (*Salt.*)		×				14.
,, Wilsoni (*Sow.*)					×	32.
,, sp.			×		×	5, 8, 15, 24, 32.
Siphonotreta (*De Verneuil*)						
,, anglica (*Morris*)		(?)			×	8, 14.
,, micula (*M'Coy*)		×	×			3, 5, 7, 8, 9, 10, 15, 16, 24, 25, 33.
,, scotica (*Dav.*)...		×				8, 14.
Skenidium (*Hall*)						
,, shallochiensis (*Dav.*)			×			7.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
BRACHIOPODA—*continued.*						
Skenidium woodlandiensis (*Dav.*) ...				×		7.
Spirifera (*Sowerby*)						
,, crispa (*His.*) ...			×	×		8, 14.
,, plicatella (*Linn.*) ...				×		8.
,, ,, var. radiata (*Sow.*) ...				×		8.
,, sulcata (*His.*) ...					×	14, 17.
Stricklandinia (*Billings*)						
,, lens (*Sow.*) ...				×		7, 8.
,, lirata (*Sow.*) ...				×		7.
Strophomena (*Rafinesque*)						
,, antiquata (*Sow.*)				×	×	7, 8, 32.
,, applanata (*Salt.*)				×	×	8, 14, 32.
,, arenacea (*Salt.*)			×			7, 15.
,, compressa (*Sow.*) ...				×		14.
,, corrugatella (*Dav.*) ...		×	×	×		7, 8, 14, 15.
,, (Rafinesquina) deltoidea (*Conr.*) ...		×	×	×		7, 8, 14, 24.
,, (Rafinesquina) ,, var. rotundata (*Conr.*)			×			15.
,, (Rafinesquina) expansa (*Sow.*) ...		×	×	×		7, 8, 14, 15.
,, filosa (*Sow.*) ...		(?)				14.
,, grandis (*Sow.*)...			×			15.
,, Grayæ (*Dav.*) ...		×				14.
,, Hendersoni (*Dav.*) ...					×	32.
,, imbrex (*Pand.*)			×			8.
,, ,, var. semiglobosa (*Dav.*)		×				14.
,, (Orthis) Kilbuchoensis (*Dav.*) ...			×			15, 24.
,, pecten (*Linn.*)...				×	×	7, 14, 32.
,, retroflexa (*Salt.*) ...		×				14.
,, (Leptæna) rhomboidalis (*Wilck.*) ...			×	×	×	7, 8, 14, 15, 23, 24, 32.
,, shallockiensis (*Dav.*) ...			(?)			24.
,, undata (*M'Coy*)				×		8.
,, Walmstedti (*Linds.*) ...					×	32.
,, sp.			×		×	5, 8, 24, 32.
Triplesia (*Hall*)						
,, Grayæ (*Dav.*) ...		×				14.
,, incerta (*Dav.*) ...				×		8
,, sp.			(?)			24.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
LAMELLIBRANCHIATA.						
Ambonychia (*Hall*)						
,, sp.			×			7, 8.
Anodontopsis (*M'Coy*)						
,, bulla (*M'Coy*)...					×	23 (?), 32.
,, lucina (*Salt.*) ...					×	23, 32.
,, (Orthonota) Salteri (*Eth., jnr.*, M.S.)					×	32.
,, sp.					×	32.
Arca (*Linnæus*)						
,, edmondiæformis (*M'Coy*)			×			7.
Avicula (*Klein*)						
,, Danbyi (*M'Coy*) ...				×		14.
Cardiola (*Broderip*)						
,, fibrosa (*Sow.*) ...					×	14, 32 (?).
,, striata (*Sow.*) ..				×		14.
,, sp.					×	32.
Cleidophorus (*Hall*)						
,, sp.		×				8.
Ctenodonta (*Salter*)						
,, anglica (*D'Orb.*)...			×			8.
,, lævis (*Sow.*) ...			×			7.
,, levata (*Hall*) ...			×			15.
,, obesa (*Salt.*) ...					×	23, 32.
,, thracioides (*Salt.*)					×	32.
,, sp.			××	×	×	5, 7, 8, 14, 15.
Cucullella (*M'Coy*)						
,, sp.			×		×	5, 7, 15, 32.
Goniophora (*Phillips*)						
,, cymbæformis (*Sow.*) ...					×	23, 32.
Grammysia (*De Verneuil*)						
,, rotundata (*Sow.*)					×	24, 32.
,, sp.					×	14.
Lunulicardium (*Münster*)						
,, elegans (*Salt.*)					×	32.
Modiolopsis (*Hall*)						
,, complanata (*Sow.*)					×	23.
,, modiolaris *Conr.*)			×			7.
,, Nilssoni (*His.*) ...					×	23.
,, orbicularis (*Sow.*)			×			15, 24.
,, sp.					×	7, 14, 32.
Mytilus (*Linné*)						
,, mytilimeris (*Conr.*)...					×	23, 24, 32.
Orthonota (*Conrad*)						
,, amygdalina (*Sow.*)					×	23, 32.
,, ,, var. gentilis (*Salt.*)					×	32.
,, bulla (*Salt,*) ..					×	32.
,, impressa (*Sow.*) ...					×	23.
,, rotundata (*Sow.*) ...					×	23.
,, simplex (*Portl.*) ...				×		14.
,, solenoides (*Sow.*) ...					×	23, 24.
,, truncata (*M'Coy*)...					×	14.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
LAMELLIBRANCHIATA—*contd.*						
Orthonota undata (*Sow.*) ..			(?)			24.
,, sp.					×	14, 23, 32.
Pleurorhynchus (*Phillips*)						
,, (Conocardium) dipterus (*Salt.*) ...			×			7, 8.
,, sp.		×				8.
Pterinea (*Goldfuss*)						
,, hyans (*M'Coy*) ...				×		14.
,, pleuroptera (*Conr.*)					×	14, 23.
,, retroflexa (*Wahl.*) ...					×	23.
,, ,, var. naviformis (*Conr.*)					×	23.
,, sowerbyana (*M'Coy*)				×		14.
,, tenuistriata (*M'Coy*)				×		14.
,, sp.			×	×	×	5, 8, 32.
GASTEROPODA.						
Acroculia (*Phillips*) (*vide* Platyceras)						
Bellerophon (*Montfort*)						
,, acutus (*Sow.*) ...		×	×			5, 7, 8, 14, 15.
,, bilobatus (*Sow.*)...			×	×		8, 14.
,, carinatus (*Sow.*)...			×		×	7, 14, 32.
,, dilatatus (*Sow.*) ..			×	×	×	8, 14, 15, 32.
,, fastigiatus (*Lindst.*)		×		(?)		7, 14.
,, perturbatus (*Sow.*)			×			14.
,, (Euomphalus) sculptus (*Sow.*) ...			×			24.
,, squamosus (*Lindst.*)				×		8.
,, subdecussatus (*M'Coy*) ...			×			14.
,, trilobatus (*Sow.*)			×		×	5, 8, 14, 15.
,, sp.		×	×		×	7, 8, 14, 32.
Chelodes (*Davidson and King*)						
,, sp.			×		×	15, 24, 32.
Cyclonema (*Hall*)						
,, crebristria (*M'Coy*)			×			7.
,, sp.			×		×	7, 15, 24, 32.
Ecculiomphalus (*Portlock*)						
,, Bucklandi (*Portl.*) ...			×			8.
,, lævis (*Sow.*)...				×		8.
,, minor (*Portl.*)			×			7.
,, scoticus (*M'Coy*) ...			×			7.
,, sp.			×			24.
Euomphalus (*Sowerby*)						
,, funatus (*Sow.*) ...					×	32.
,, sp.			×		×	15, 32.
Holopea (*Hall*)						
,, concinna (*M'Coy*) ...			×			24.
,, sp.		×				8.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
GASTEROPODA—*continued.*						
Holopella (*M'Coy*)						
,, obsoleta (*Sow.*) ...			×	×		14, 23.
,, sp.			×		×	15, 32.
Loxonema (*Phillips*)						
,, sinuosum (*Sow.*) ...			×			14.
,, sp.			×		×	5, 14, 24.
Maclurea (*Lesueur*)						
,, Logani (*Salt.*) ...		×	(?)			7, 8.
,, Maccoyi (*Salt.*) ...		×				8.
,, (Ophileta) macromphala (*M'Coy*)		×	×			8, 15.
,, magna (*Lesu.*) ...		×				7, 8.
,, matutina (*Hall*) ...		×				8.
,, sp.			×			14, 15.
Macrochilina (*Bayle*)						
,, elongata (*Portl.*)				×		14.
,, sp.			×			15.
,, sp.		×	×			8, 15.
Metoptoma (*Phillips*)						
,, (Tryblidium) sp.		×	×			8, 14.
Murchisonia (*D'Archiac et De Verneuil*)						
,, angulata (*Sow.*)...			×			24.
,, (Pleurotomaria) bicincta (*Hall*) ...		×				7, 8.
,, cancellatula (*M'Coy*) ...			×	×		14.
,, elongata (?) (*Portl.*)				×		14.
,, gracilis (*Hall*) ...		×				8.
,, gyrogonia (*M'Coy*)		×	×			7, 8, 15.
,, obscura (*Portl.*)...					×	5.
,, pulchra (*M'Coy*)			×			14.
,, (Pleurotomaria) turrita (*Portl.*)			×			14.
,, vitellia (*Bill.*) ...		×				8.
,, sp.			×		×	5, 14, 15, 23, 24.
Ophileta (*Vanuxem*)						
,, compacta (*Salt.*) ...			×			7, 8.
Platyceras (*Conrad*)						
,, (Acroculia) antiquatum (*Salt.*)					×	24, 32.
,, cornutum (*His.*) ...				×	×	8, 24, 32.
,, Gibbsi (*Eth., jnr.*, M.S.) ...					×	32.
Platyschisma (*M'Coy*)						
,, (Trochus) helicites (*Sow.*)			(?)		×	23, 24, 32.
,, simulans (*Salt.*)					×	24, 32.
,, sp.					×	32.
Pleurotomaria (*Defrance*)						
,, alata (*Wahl.*)...			×			14, 15.
,, æquilatera (*Wahl.*) ...			×			14, 15.
elliptica (*His.*)			×			15, 24.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
GASTEROPODA—*continued.*						
Pleurotomaria helicina (*Lindst.*)					×	24, 32.
,, (Raphistoma) lenticularis (*Sow.*) ...		×	×			7, 8, 14, 15, 24.
,, Moorei (*Salt.*)			×			14.
,, (Euomphalus) qualteriata (*Schl.*) ...		×		×		8.
,, sp.		×	×		×	8, 14, 24, 32.
Raphistoma (*Hall*)						
,, æqualis (*Salt.*) ...			×			8.
Tremanotus (*Hall*)						
,, longitudinalis (*Lindst.*) ...					×	24, 32.
Trochus (*Linnæus*)						
,, sp.		×				8.
Turbo (*Linnæus*)						
,, sp.			×			15.
PTEROPODA.						
Conularia (*Miller*)						
,, elongata (*Portl.*) ...			×			14, 15.
,, Sowerbyi (*Defr.*) ...			×	×	×	14, 32.
,, sp.			×		×	24, 32.
Hyolithes (*Eichwald*)						
,, aduncus (*Barr.*) ...					×	5.
,, (Theca) corrugatus (*Sall.*) ...			×			14.
,, ,, Forbesi (*Sharpe*) ...					×	23.
,, ,, reversus (*Salt.*) ...			×		×	7, 10.
,, ,, triangularis (*Portl.*) ...			×			7, 14.
,, ,, vaginulus (*Salt.*) ...			×			7, 14.
,, sp.		×	×	×	×	7, 8, 14, 15, 16, 24, 32.
Pterotheca (*Salter*)						
,, corrugata (*Salt.*)...			×			15.
CEPHALOPODA.						
Cyrtoceras (*Goldfuss*)						
,, (?) inæquiseptum (*Portl.*) ...		×				8.
,, scoticum (*Blake*) ...			×			24.
,, sp.		×			×	8, 17.
Gomphoceras (*Sowerby*)						
,, ellipticum (*M'Coy*) ...					×	32.
,, sp.				×	×	14, 32.
Lituites (*Breynius*)						
,, (Nautilus) sp. ...			×		×	8, 15, 32.
,, (Trocholites) cornu-arietis (*Sow.*)			×			24.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
CEPHALOPODA—*continued.*						
Orthoceras (*Breynius*)						
,, angulatum (*Wahl.*)			×		×	14, 15.
,, annulatum (*Sow.*)					×	5, 10, 11, 17.
,, arcuoliratum (*Hall*)			×			24.
,, argus (*Barr.*) ...			(?)			14.
,, canaliculatum = (angulatum) (*Sow.*) ...			×			8.
,, coralliforme (*M'Coy*)			×			8.
,, dimidiatum (*Sow.*)					×	23.
,, Etheridgei (*Blake*)					×	5.
,, fimbriatum (*Sow.*)				×	×	5, 8.
,, gracile (*Portl.*) ...					×	15, 23.
,, Grayi (*Blake*) ...				×		8.
,, ibex (*Sow.*) ...			(?)			7.
,, imbricatum (*Wahl.*)			×			7.
,, MacLareni (*Salt.*)					×	14, 15, 32.
,, nicholianum (*Blake*) ..					×	10.
,, pendens (*Blake*) ...		×	×			8, 14, 24.
,, politum (*M'Coy*)...		×	×		×	5, 8, 14.
,, pomeroense (*Portl.*)					(?)	15.
,, semipartitum (*Sow.*)					×	32.
,, subundulatum (*Portl.*) ...			×		×	5, 8, 14, 32.
,, tenuicinctum = (elongato-cinctum) (*Portl.*) ...					×	5.
,, vaginatum (*Schl.*)				×		14 (?).
,, sp.		×	×		×	2, 5, 7, 8, 9, 10, 11, 14, 15, 17, 18, 23, 24, 32.
PISCES.						
Ateleaspis (*Traquair*)						
,, tessellata (*Traq.*)..					×	15, 23, 32.
Birkenia (*Traquair*)						
,, elegans (*Traq.*) ...					×	15, 23, 32.
Lanarkia (*Traquair*)						
,, horrida (*Traq.*) ...					×	15, 23.
,, spinosa (*Traq.*) ...					×	15, 23.
,, spinulosa (*Traq.*) ...					×	15, 23.
Lasanius (*Traquair*)						
,, problematicus (*Traq.*)					×	15, 23, 32.
Thelodus (*Agassiz*)						
,, planus (*Traq.*) ...					×	23.
,, scoticus (*Traq.*) ...					×	15, 23.
INCERTÆ SEDIS.						
Dictyocaris (*Salter*)						
,, Ramsayi (*Salt.*)...					×	11, 24, 32.
,, Slimoni (*Salt.*) ...					×	23.
,, sp.				×	×	5, 8, 10, 17, 23, 25, 32.
Crossochorda (*Schimper*)						
,, sp.				×		25.

	Arenig.	Llandeilo.	Caradoc.	Llandovery.	Wenlock-Ludlow.	One-inch Maps.
INCERTÆ SEDIS—*continued.*						
Crossopodia (*M'Coy*)						
,, scotica (*M'Coy*)				×		16, 17, 25.
,, sp.				×		25.
Dexolites (*Hopkinson*)						
,, gracilis (*Hopk.*) ...				×		16, 25.
,, sp.				×		25.
Eione (*Tate*)						
,, sp.				×		17.
Myrianites (*M'Leay*)						
,, tenuis (*M'Coy*) ...				×		16, 24, 25, 33, 34.
Nemertites (*M'Leay*)						
,, sp....				×		8, 24, 33.
Nereites (*M'Leay*)						
,, cambrensis (*Murch.*)				×		8.
Protovirgularia (*M'Coy*)						
,, dichotoma (*M'Coy*) ...				×		10, 17, 25.
,, Harknessi (*Lapw.*) ...				×		5, 10, 25.
,, sp.				×		4.
Various tracks...				×		5, 10, 17, 25, 33.
Branching tracks				×		25.
Fucoids (?)				×		25.

No. 3.—List of Fossils Prepared by Mrs. Gray from the Collection made by her from the Silurian Rocks of the Girvan District of the South of Scotland.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
Miscellaneous.								
Chondrites sp.	×							Penkill.
Girvanella problematica (*N. and E.*)							×	Tramitchell.
Nidulites favus (*Salter*)		×	×					Mulloch Hill. Newlands.
Ischadites Königi (*Murch.*)							×	Balclatchie.
„ antiquus (*Salter*)	×	×						Penkill. Woodland Point.
„ sp.		×						Newlands.
Saccammina Carteri (*Brady*)							×	Craighead.
Clathrodictyon vesiculosum (*N. and Murie*)		×						Woodland Point.
Actinozoa.								
Calostylis Lindströmi (*N. & E.*)	×							Penkill.
Favosites girvanensis (*N. & E.*)							×	Craighead.
„ mullochensis (*N. & E.*)		×	×					Mulloch Hill. Woodland Point.
Fistulipora favosa (*N. and E.*)							×	Balclatchie Conglomerate.
„ pilula (*N. and E.*)							×	Craighead.
Halysites catenularia (*Linn.*)	×	×	×	×	×		×	Penkill. Woodland Point, Shalloch Forge, Newlands. Mulloch Hill, Rough Neuk. Starfish Bed. Shalloch Mill. Craighead.
„ sp.					×			Shalloch Mill.
„ sp.		×						Woodland Point.
Heliolites Grayi (*M. Edw. & H.*)							×	Craighead.
„ interstincta (*Linn.*)	×	×	×					Mulloch Hill, Rough Neuk. Woodland Point. Penkill.
„ foliacea (*N. and E.*)		×						Woodland Point.
„ parasitica (*N. and E.*)			×					Mulloch Hill, Rough Neuk, Craigens Quarry.
Labechia canadensis (*N. & Murie*)							×	Aldons.
Lindströmia subduplicata (*M'Coy*)			×				×	Mulloch Hill. Craighead.
Lyopora favosa sp. (*M'Coy*)							×	Craighead.
Monticulipora girvanensis (*Nich.*)							×	Craighead.
Pinacopora Andersoni (*N. & E.*)		×						Woodland Point.
„ Grayi (*N. and E.*)		×	×					Mulloch Hill, Rough Neuk, Craigens Quarry. Newlands.
Propora Edwardsi (*N. and E.*)							×	Craighead.
Prasopora Grayæ (*N. and E.*)							×	Craighead.
Plasmopora girvanensis (*N. and E.*)	×	×						Woodland Point. Penkill.
Streptelasma craigense (*M'Coy*)							×	Craighead.
„ aggregatum (*N. and E.*)							×	Craighead.
„ Europæum (*Röm.*)							×	Craighead.
„ æquisulcatum (*M'Coy*)			×					Mulloch Hill, Rough Neuk.
Tetradium Peachi (*N. and E.*)							×	Craighead.
Thecostegites scoticus (*N. and E.*)							×	Craighead.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
ECHINODERMATA.								
Tetraster Wyv.-Thomsoni (*E. and N.*)				×				Starfish Bed, Thraive.
,, sp.				×				Starfish Bed.
Palæaster sp.							×	Dow Hill.
CRINOIDEA.								
Glyptocrinus			×					Mulloch Hill, Rough Neuk, Crinoid Bed, High Road.
,, sp.							×	Craighead.
,, sp.							×	Craighead.
,, sp.				×				Starfish Bed.
,, sp.							×	Balclatchie, Ardmillan, Dow Hill.
,, sp.					×			Shalloch Mill.
,, sp.		×						Woodland Point, Newlands.
,, sp.	×							Penkill, Bargany Pond Burn.
Myelodactylus ?	×							Penkill.
CYSTOIDEA.								
Pleurocystites sp.				×				Starfish Bed.
,, sp.				×				Starfish Bed.
ANNELIDA.								
Serpulites longissimus (*Murch.*)				×				Thraive Glen.
,, ?					×			Whitehouse Bay.
Tentaculites ornatus (*Sow.*)		×						Woodland Point.
,, sp.							×	Dow Hill.
,, anglicus (*Salter*)			×		×			Shalloch Mill.
								Mulloch Hill, Rough Neuk.
		×						Woodland Point, Newlands.
	×							Camregan Wood.
Cornulites sp.							×	Craighead.
Nereites cambrensis (*Murch.*)	×							Penwhapple Glen.
Myrianites tenuis (*M'Coy*)	×							Penwhapple Glen.
,, sp.	×							Penwhapple Glen.
Crossopodia scotica (*M'Coy*)	×							Penwhapple Glen.
,, sp.	×							Penwhapple Glen.
Nemertites sp.	×							Penwhapple Glen.
Eione ?	×							Penwhapple Glen.
Olnencites sp. (jaws of)							×	Balclatchie.
HYDROZOA.								
Climacograptus normalis (*Lapw.*)		×						Woodland Point.
,, scalaris (*Hisinger*)						×		Penwhapple Glen, Waterfall.
,, bicornis (*Hall*)							×	Craighead.
,, tubuliferus (*Lapw.*)						×		Waterfall, Penwhapple Glen.
					×			Myoch Burn, Shalloch.
,, Schärenbergi (*Lapw.*)							×	Craighead, Balclatchie Conglomerate,
Cryptograptus tricornis (*Carr.*)							×	Craighead.
Cyrtograptus Grayæ (*Lapw.*)	×							Penwhapple Glen.
Dicellograptus Morrisi (*Hopk.*)					×			Whitehouse Bay, Myoch Burn.
,, anceps (*Nich.*)				×				Thraive Glen.
,, moffatensis (*Lapw.*)							×	Ardmillan.
Dicranograptus tardiusculus (*Lapw.*)							×	Balclatchie, Ardmillan.
,, ramosus (*Hall*)							×	Craighead.
Dimorphograptus sp.			(?)					Whitehouse Bay.
Diplograptus tamariscus (*Nich.*)		×						Shalloch Forge.
,, bullatus (*Salter*)		×						Shalloch Forge.
,, quadrimucronatus (*Hall*)					×			Whitehouse Bay.
,, vesiculosus (*Nich.*)		×						Woodland Point.
,, modestus (*Lapw.*)			(?)					Whitehouse Bay, Shalloch Mill.
		×						Woodland Point.
,, truncatus (*Lapw.*)					×			Whitehouse Bay, Myoch Burn.
				×				Thraive Glen.
							×	Ardwell.
,, rugosus (*Emm.*)							×	Ardwell, Craighead, Balclatchie.
,, sp.				×				Starfish Bed.
foliaceous (*Murch.*)							×	Letterpin, Craighead; Waterfall, Penwhapple.
					×			Myoch Burn.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
HYDROZOA—*continued.*								
Diplograptus sp.							×	Craighead, Pinmore.
,, sp.			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Dow Hill, Ardmillan.
,, socialis (*Lapw.*)					×			Whitehouse Bay.
Monograptus galaensis (*Lapw.*)	×							Penkill, Penwhapple Glen.
,, Hisingeri (*Carr.*)	×							Penkill, Penwhapple.
,, spiralis (*Geis.*)	×							Penkill, Penwhapple.
,, concinnus (*Lapw.*)	×							Penwhapple Glen.
,, exiguus (*Nich.*)	×							Penwhapple Glen.
,, reversus (*Kurck.*)			(?)					Whitehouse Bay.
,, tenuis (*Portl.*)		×						Woodland Point.
,, gregarius (*Lapw.*)		×						Woodland Point.
,, leptotheca (*Lapw.*)		×						Woodland Point.
,, colonus (*Barr.*)	×							Penwhapple Glen.
,, priodon (*Bronn.*)	×							Penwhapple Glen.
,, Sedgwicki (*M'Coy*)	×							Penwhapple Glen.
Ptilograptus sp.		×						Mulloch Hill, Ptilograptus Bed.
Rastrites peregrinus (*Barr.*)	×							Penwhapple Glen.
Retiolites geinitzanus (*Barr.*)	×							Penwhapple Glen.
Nematolites Grayi (*Lapw.*)					×			Shalloch Mill.
,, ,,		×						Woodland Point.
Leptograptus flaccidus (*Lapw.*)						×		Waterfall, Penwhapple Glen.
Dictyonema delicatulum (*Lapw.*)	×							Shalloch Forge.
TRILOBITA.								
Acidaspis hystrix (*Wyv.-Thom.*)							×	Balclatchie.
,, lalage (*Wyv.-Thom.*)							×	Balclatchie.
,, Grayæ (*R. Eth., jnr.*)							×	Balclatchie.
,, Brighti (*Murch.*)		×						Woodland Point.
,, sp.			×					Mulloch Hill, Rough Neuk.
,, bispinosa (*M'Coy*)	×							Penkill.
,, sp.		×						Newlands.
Agnostus agnostiformis (*M'Coy*)							×	Balclatchie, Ardmillan, Dow Hill.
,, perrugatus (*Barr.*)				×				Whitehouse Bay.
Ampyx Macalluni (*Salter*)							×	Balclatchie, Dow Hill.
,, Hornei (*E. and N.*)							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
,, sp.					×			Whitehouse Bay.
,, sp.							×	Benan Burn, Balclatchie Conglomerate
,, rostratus (*Sars*)				×				Drummock, Starfish Bed, Thraive Glen.
Asaphus gigas (*Dekay*)							×	Dow Hill, Balclatchie, Ardmillan, Minuntion.
,, marginatus (*Portl.*)				×				Starfish Bed.
Bohemilla sp.					×			Whitehouse Bay.
Bronteus Andersoni (*N. and E.*)	×							Penkill, Bargany Pond Burn.
		×						Woodland Point, Newlands.
Bronteopsis scotica (*Salter*)							×	Balclatchie, Ardmillan.
Calymene Blumenbachi (*Brong.*)	×							Penkill, Cuddystone Glen.
		×						Woodland Point, Newlands.
			×		×			Mulloch Hill, all the Quarries.
								Shalloch Mill.
				×				Thraive Glen, Starfish Bed.
							×	Craighead.
Cheirurus bimucronatus (*Murch.*)	×							Bargany Pond Burn, Penwhapple Glen.
		×						Woodland Point.
				×				Thraive Glen.
							×	Craighead, Minuntion, Balclatchie Conglomerate.
,, sp.							×	Balclatchie, Ardmillan.
,, trispinosus (*Young*)	×							Penkill.
,, Sedgwicki (*M'Coy*)							×	Balclatchie.
,, gelasinosus (*Portlock*)							×	Balclatchie.
,, clavifrons (*Dalm.*)				×				Thraive Glen.
Cybele rugosa (*Portlock*)				×				Thraive Glen.
,, verrucosa (*Dalm.*)							×	Ardmillan, Balclatchie, Dow Hill.
,, sp.					×			Shalloch Mill.
Cyclopyge rediviva (*Barr.*)					×			Whitehouse Bay.
,, armata (*Barr.*)					×			Whitehouse Bay.
Deiphon Forbesi (*Barr.*)							×	Balclatchie.
Dionide Lapworthi (*E. and N.*)					×			Whitehouse Bay.
,, sp.					×			Whitehouse Bay.
,, sp.				×				Thraive Glen.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
TRILOBITA—*continued.*								
Dindymene Cordai (*E. and N.*)				×				Drummuck, Thraive.
Dindymene Cordai (*E. and N.*)					×			Whitehouse Bay.
,, sp.							×	Auchensoul.
Encrinurus punctatus, var. calcareus (*Salter*)	×							Penkill.
Encrinurus punctatus, var. calcareus (*Salter*)		×						Woodland Point.
Encrinurus punctatus, var. calcareus (*Salter*)	×							Penkill, Bargany Pond Burn, Camregan Wood.
Encrinurus punctatus, var. arenaceus (*Salt.*)		×						Woodland Point, Newlands.
Encrinurus punctatus, var. arenaceus (*Salt.*)			×					Mulloch Hill, Rough Neuk, High Road.
Encrinurus punctatus, var. arenaceus (*Salt.*)							×	Craighead.
Harpes sp.							×	Balclatchie, Ardmillan, Aldons.
,, sp.	×							Bargany Pond Burn.
Illænus Bowmani (*Salter*)							×	Balclatchie, Ardmillan, Craighead, Minuntion.
,, nexilis (*Salter*)				×				Drummuck.
,, nexilis (*Salter*)	×							Penkill, Bargany Pond Burn.
,, (Bumastus) barriensis (*Murch.*)		×						Woodland Point.
,, sp.	×							Camregan Wood.
,, sp.					×			Shalloch Mill.
,, Thomsoni (*Salter*)			×					Mulloch Hill, Rough Neuk, Craigens Quarry.
,, Thomsoni (*Salter*)		×						Woodland Point.
,, Murchisoni (*Salter*)	×							Penkill.
,, simulus (*Salter*)	×							Penkill.
,, Rosenbergi (*Eichwald*)	×							Penkill.
Lichas hibernicus (*Portlock*)							×	Balclatchie, Craighead.
,, Geikiei (*E. and N.*)				×				Thraive Glen.
,, laxatus (*M'Coy*) ?				×				Thraive Glen.
,, palmatus (*Barr.*) ?			×					Mulloch Hill, Rough Neuk.
,, ambiguus (*Barr.*)			×					Mulloch Hill, Rough Neuk, Craigens Quarry.
,, ambiguus (*Barr.*)		×						Newlands.
,, Grayi (*Fletcher*)							×	Balclatchie.
,, sp.							×	Dow Hill.
,, sp.	×							Camregan Wood.
,, sp.		×						Woodland Point.
Phacops Brongniarti (*Portlock*)							×	Ardmillan, Dow Hill, Minuntion, Balclatchie.
Phacops Brongniarti (*Portlock*)				×				Starfish Bed.
Phacops Brongniarti (*Portlock*)			×					Mulloch Hill, all the Quarries.
Phacops Stokesi (*M. Edw.*)		×						Newlands.
Phacops Stokesi (*M. Edw.*)	×							Penkill, Bargany Pond Burn, Camregan Wood.
,, Downingiæ (*Murch.*)		×						Woodland Point.
,, Downingiæ (*Murch.*)			×					Mulloch Hill, Rough Neuk.
Proetus girvanensis (*E. and N.*)				×				Thraive Glen.
,, procerus (*E. and N.*)				×				Thraive Glen.
,, sp.			×					Mulloch Hill, High Road.
,, sp.	×							Camregan Wood.
Phillipsia parabola (*Barr.*)				×				Thraive Glen, Starfish Bed.
Staurocephalus unicus (*Portlock*)							×	Balclatchie, Dow Hill.
Staurocephalus unicus (*Portlock*)			×					Mulloch Hill, Rough Neuk.
Staurocephalus unicus (*Portlock*)							×	Balclatchie, Dow Hill, Ardmillan.
,, globiceps (*Wyv. Thom.*)					×			Shalloch Mill.
,, globiceps (*Wyv. Thom.*)				×				Thraive Glen, Starfish Bed.
,, globiceps (*Wyv. Thom.*)		×						Woodland Point, Newlands.
,, sp.	×							Bargany Pond Burn.
Sphærexochus mirus (*Beyrich*)							×	Craighead, Balclatchie conglomerate.
Stygina latifrons (*Portlock*)							×	Ardmillan.
Trinucleus concentricus (*Eaton*)							×	Dow Hill.
,, Macconochiei (*E. & N.*)							×	Balclatchie.
,, seticornis His., var. Bucklandi (*Barr.*)				×				Drummuck, Thraive, Starfish Bed.
,, sp.					×			Whitehouse Bay.
,, sp.					×			Shalloch Mill.
,, sp.							×	Craighead.
OSTRACODA.								
Aparchites leperditioides (*Jones*)					×			Whitehouse Bay.
,, subovatus (*Jones*)					×			Whitehouse Bay.
Primitia elongata (*Krause*) var. nuda (*Jones*)					×			Whitehouse Bay.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
OSTRACODA—*continued.*								
Primitia Krausei (*Jones*) ..					×			Whitehouse Bay.
,, girvanensis (*Jones*) ..					×			Whitehouse Bay.
,, Grayæ (*Jones*)					×			Whitehouse Bay.
,, mundula, var. fimbriata (*Jones*) ..					×			Whitehouse Bay.
,, mundula, var. klœdeniana (*Jones*)..					×			Whitehouse Bay.
,, ulrichiana (*Jones*) ..					×			Whitehouse Bay.
,, barrandiana (*Jones*) ..							×	Aldons.
Beyrichia Klœdeni (*M'Coy*) ..				×				Thraive Glen, Whitehouse Bay.
,, ,, var. infecta (*Jones*) ..					×			Whitehouse Bay.
,, ,, var. Scotica (*Jones & Holl.*)	×							Bargany Pond Burn.
,, impar (*Jones*)					×			Whitehouse Bay.
,, comma (*Jones*).. ..				×				Thraive Glen.
Ulrichia girvanensis (*Jones*) .					×			Whitehouse Bay.
,, sp.					×			Whitehouse Bay.
,, Grayæ (*Jones*)	×							Bargany Pond Burn.
Sulcuna præurrens (*Jones*) ..					×			Whitehouse Bay.
Cypridina Grayæ (*Jones*) ..					×			Whitehouse Bay.
Cythere aldensis (*M'Coy*) ..							×	Aldons.
,, ,, var. major (*Jones*) ..							×	Aldons.
,, grayana (*Jones*) ..							×	Aldons.
,, wrightiana (*Jones and Holl.*)							×	Aldons.
,, sp.		×						Newlands.
,, sp.							×	Auchensoul.
PHYLLOPODA AND CIRREPEDIA.								
Pinnocaris Lapworthi (*Eth., jun.*) ..							×	Balclatchie, Ardmillan.
,, sp.				×				Drummock, Starfish Bed.
Turrilepas Peachi (*E. and N.*) ..					×			Whitehouse Bay.
,, sp.				×				Thraive Glen.
,, scotica (*E. and N.*) ..							×	Balclatchie, Dow Hill, Ardmillan.
,, sp.		×						Newlands.
POLYZOA.								
Fenestella assimilis (*Lonsd.*) ..		×						Woodland Point.
,, patula (*M'Coy*) ..	×							Penkill.
		×						Woodland Point.
,, Milleri (*Lonsd.*) ..		×						Woodland Point.
,, subantiqua (*D'Orbigny*) ..	×							Penkill.
		×						Woodland Point.
,, sp.			×					Mulloch Hill, Rough Neuk.
,, sp.			×					Mulloch Hill, High Road.
,, sp.		×						Newlands.
,, sp.					×			Shalloch Mill.
Glauconome disticha (*Goldf.*) ..		×						Woodland Point.
Gorgonia regularis (*Portl.*) ..		×						Woodland Point.
Hippothoa inflata (*Nich.*) ..		×						Woodland Point.
Rhinopora verrucosa (*Hall*) ..		×						Woodland Point.
Retepora sp.							×	Balclatchie.
			×					Mulloch Hill, Rough Neuk.
Ptilodictya costellata (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, dichotoma (*Portl.*) ..							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
		×						Woodland Point.
	×							Penkill, Bargany Pond Burn.
,, sp.							×	Dow Hill.
,, lanceolata (*Goldf.*) ..		×						Woodland Point.
BRACHIOPODA.								
Lingula canadensis (*Billings*) ..							×	Balclatchie conglomerate.
,, quadrata (*Eichwald*) ..					×			Shalloch Mill.
							×	Craighead.
,, Ramsayi (*Salter*) ..							×	Craighead, Balclatchie, Minuntion.
,, granulata (*Phillips*) ..							×	Ardmillan, Balclatchie, Minuntion.
,, attenuata (*Sow.*) ..				×				Drummuck.
					×			Shalloch Mill, Whitehouse Bay.
							×	Balclatchie, Ardmillan, Dow Hill.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Lingula ovata (*M'Coy*)							×	Craighead.
				×				Drummuck.
			×					Mulloch Hill, Rough Neuk.
,, brevis (*Portlock*)							×	Ardmillan.
					×			Shalloch Mill, Whitehouse Bay.
,, Symondsi (*Salter*)	×							Penkill, Bargany Pond Burn.
		×						Woodland Point.
Dinobolus Davidsoni (*Salter*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
Orbiculoidea Forbesi (*Dav.*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
Discina oblongata (*Portl.*)							×	Balclatchie, Ardmillan, Dow Hill.
,, perrugata (*M'Coy*)							×	Balclatchie, Ardmillan, Craighead.
					×			Shalloch Mill.
,, crassa (*Hall*)?	×							Penwhapple Glen.
,, rugata (*Sow.*)	×							Bargany Pond Burn.
Paterula balcletchiensis (*Dav.*)				×			×	Balclatchie.
								Starfish Bed, Thraive.
Siphonotreta scotica (*Dav.*)				×			×	Craighead, Minuntion, Starfish Bed.
,, micula *M'Coy*)							×	Balclatchie, Ardmillan.
Acrothele granulata (*Linnr.*)							×	Dow Hill.
		×						Woodland Point.
Crania siluriana (*Dav.*)			×					Mulloch Hill, Rough Neuk, High Road Quarries.
,, llandoveriana (*Dav.*)		×						Newlands.
,, sp.				×				Starfish Bed, Thraive.
,, sp.			×				×	Ardmillan, Craighead.
								Mulloch Hill, Rough Neuk, High Road Quarries.
,, sp.	×							Penkill.
Pholidops implicata (*Sow.*)		×						Woodland Point, Newlands.
					×			Shalloch Mill.
	×							Bargany Pond Burn.
Acrotreta Nicholsoni (*Dav.*)							×	Craighead, Balclatchie, Ardmillan.
,, costata (*Dav.*)							×	Balclatchie.
Spirifera plicatella, var. radiata (*Sow.*)	×							Bargany Pond Burn, Penkill.
Cyrtia exporrecta (*Wahl.*)	×							Penkill.
Nucleospira pisum (*Sow.*)	×							Bargany Pond Burn.
Meristella (Whitfieldia) tumida (*Dalm.*)	×							Bargany Pond Burn.
,, angustifrons (*M'Coy*)			×					Mulloch Hill, Rough Neuk, High Road.
				×				Auldthorns.
Athyris sp.					×			Whitehouse Bay.
Glassia obovata (*Sow.*)	×							Penkill.
Merista cymbula (*Dav.*)				×				Thraive, Drummuck.
Atrypa reticularis (*Linn.*)	×							Penkill, Penkill Limestone, Penwhapple Glen.
		×						Woodland Point.
			×					Mulloch Hill, Rough Neuk, High Road.
,, imbricata (*Sow.*)	×							Penkill, Bargany Pond Burn.
		×						Woodland Point.
,, scotica (*M'Coy*)?			×					Mulloch Hill.
Triplesia Grayæ (*Dav.*)							×	Craighead.
,, spiriferoides (*M'Coy*)				×				Starfish Bed, Thraive Glen.
,, monilifera (*M'Coy*)							×	Ardmillan.
,, incerta (*Dav.*)	×	×						Woodland Point.
								Penkill, Bargany Pond Burn, Cuddystone Glen.
,, sp.							×	Craighead.
Porambonites intercedens (*Pander*)					×			Shalloch Mill.
Leptocœlia hemispherica (*Sow.*)	×							Camregan Wood.
				×				Auldthorns.
			×					Mulloch Hill, Rough Neuk, High Road.
Pentamerus oblongus (*Sow.*)	×							Penkill, Cuddystone Glen.
		×						Newlands.
,, globosus (*Sow.*)	×							Penkill.
,, undatus (*Sow.*)		×	×					Woodland Point, Newlands, Ptilograptus Bed, Craigens Quarry.
	×							Penkill, Cuddystone Glen.
,, galeatus (*Sow.*)	×							Penkill.
,, rotundus (*Sow.*)	×							Penkill, Penkill Beds, Penwhapple Glen.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
Brachiopoda—*continued.*								
Pentamerus shallockiensis (*Dav.*)? ..					×			Shalloch Mill.
Stricklandinia lens (*Sow.*) ..		×	×					Woodland Point, Newlands, Mulloch Hill, Rough Neuk.
,, lirata (*Sow.*) ..		×						Woodland Point.
,, balclatchiensis (*Dav.*)							×	Balclatchie conglomerate.
Rhynchonella emula (*Salter*) ..							×	Craighead.
,, Salteri (*Dav.*) ..							×	Craighead.
,, nasuta (*M'Coy*) ..							×	Craighead, Balclatchie, Minuntion.
,, Thomsoni (*Dav.*) ..							×	Craighead.
,, portlockiana (*Dav.*)							×	Craighead, Balclatchie.
,, Lapworthi (*Dav.*) ..							×	Craighead.
,, sub-borealis (*Dav.*)							×	Craighead.
,, cuneata (*Dalm.*) ..			×	×				Mulloch Hill, Rough Neuk, High Road.
	×							Auldthorns.
								Camregan Wood.
,, cuneata, var. ardmillanensis (*Dav.*)							×	Ardmillan.
,, cuneatella (*Dav.*) ..							×	Balclatchie conglomerate.
,, Peachi (*Dav.*) ..							×	Craighead.
,, Weaveri (*Salter*) ..							×	Craighead.
,, llandoveriana (*Dav.*)	×							Camregan Wood.
,, nucula (*Sow.*)? ..							×	Balclatchie conglomerate.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
,, scotica (*Dav.*) ..							×	Craighead.
,, girvanensis (*Dav.*)							×	Balclatchie conglomerate.
,, Wilsoni (*Sow.*) ..	×							Camregan Wood.
,, balclatchiensis (*Dav.*) ..							×	Balclatchie, Craighead, Minuntion.
,, decemplicata (*Sow.*)			×					Mulloch Hill.
,, sp.							×	Craighead, Balclatchie conglomerate.
,, sp.		×						Newlands.
,, sp.							×	Dow Hill, Ardmillan.
,, sp.				×				Starfish Bed, Thraive Glen.
Skenidium Lewisii, var. woodlandensis (*Dav.*)		×						Woodland Point.
,, Grayi (*Dav.*).. ..				×				Starfish Bed, Thraive Glen.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
					×			Shalloch Mill.
Orthis biloba (*Linn.*)		×						Woodland Point.
	×							Bargany Pond Burn.
,, polygramma, var. ententlandica (*Dav.*)	×							Penkill.
		×						Woodland Point.
,, turgida (*M'Coy*) ..	×							Penkill Limestone, Penwhapple Glen.
							×	Craighead, Balclatchie conglomerate.
,, Bouchardi, var. balclatchiensis (*Dav.*) ..							×	Craighead, Balclatchie conglomerate.
,, biforata (*Schloth.*)							×	Craighead.
	×							Penkill Limestone, Penwhapple Glen.
,, calligramma (*Dalm.*) ..					×			Shalloch Mill.
							×	Craighead, Aldons, Tramitchell.
							×	Ardmillan, Minuntion.
		×						Shalloch Forge.
,, ,, var. scotica (*Dav.*) ..							×	Craighead.
,, ,, var. virgata (*Salter*) ..							×	Balclatchie Beds, Doularg.
,, ,, var. plicata (*Sow.*) ..							×	Balclatchie Beds, Ardmillan.
		×						Woodland Plint.
,, mullockensis (*Dav.*) ..			×					Mulloch Hill, Rough Neuk, High Road.
				×				Auldthorns, Starfish Bed, Thraive Glen.
,, confinis (*Salter*)							×	Minuntion, Benan Burn, Doularg, Tramitchell.
,, vespertillio (*Sow.*)..							×	Craighead.
					×			Shalloch Mill.
,, girvanensis (*Dav.*) ..							×	Craighead.
,, intercostata (*Portl.*) ..							×	Aldons.
,, Lapworthi (*Dav.*).. ..					×			Shalloch Mill.
							×	Balclatchie conglomerate.
,, testudinaria (*Dal.*) ..					×			Shalloch Mill.
							×	Craighead, Balclatchie, Dow Hill, Ardmillan.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Orthis flabellulum (*Sow.*)				×				Starfish Bed, Thraive Glen.
							×	Craighead, Ardmillan.
,, crispa (*M'Coy*)				×				Starfish Bed.
							×	Ardmillan.
,, kilbuchoensis (*Dav.*) ..							×	Ardmillan.
,, sagittifera (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, sowerbyana (*Dav.*) ..				×				Starfish Bed.
					×			Shalloch Mill.
							×	Craighead, Balclatchie conglomerate.
	×							Penkill, Bargany Pond Burn.
		×						Newlands, Woodland Point.
,, elegantula (*Dal.*)			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
				×				Thraive Glen.
					×			Shalloch Mill.
							×	Craighead, Balclatchie.
,, nina (*Dav.*)					×			Whitehouse Bay.
,, rustica (*Sow.*)			×					Mulloch Hill, Rough Neuk, and in Wood.
	×							Cuddystone Glen, Penkill Beds, Penwhapple Glen.
,, ,, var. rigida (*Dav.*)		×						Woodland Point.
	×							Penkill Beds, Penwhapple Glen.
,, Actoniæ (*Sow.*)				×				Starfish Bed.
,, reversa (*Salter*)	×							Penkill Beds, Penwhapple Glen.
,, protensa (*Sow.*)							×	Benan Crag.
,, Rankini (*Dav.*)				×				Starfish Bed.
							×	Ardmillan.
,, Carausii (*Salter*)							×	Ardmillan.
,, sp.					×			Shalloch Mill.
,, sp.							×	Balclatchie Beds.
,, sp.							×	Ardmillan.
,, sp.				×				Starfish Bed.
Strophomena Walmstedti (*Linds.*)	×							Cuddystone Glen.
	×							Penkill, Penwhapple Glen.
		×						Newlands, Woodland Point.
			×					Mulloch Hill, Rough Neuk, Craigens, Ptilograptus Bed.
Strophomena rhomboidalis (*Wilck.*) ..				×				Starfish Bed, Thraive Glen, Auldthorns.
					×			Shalloch Mill.
							×	Craighead.
,, applanata (*Salter*)	×							Penkill, Bargany Pond Burn, Cuddystone Glen.
		×						Newlands.
,, pecten (*Linn.*) ..		×						Newlands, Woodland Point.
	×							Bargany Pond Burn, Penkill.
,, antiquata (*Sow.*) ..		×						Woodland Point.
			×					Mulloch Hill, Rough Neuk.
,, imbrex, var. semiglobosina (*Dav.*)							×	Craighead, Balclatchie conglomerate.
,, compressa (*Sow.*) ..	×							Camregan Wood.
							×	Ardmillan.
,, simulans (*M'Coy*) ..					×			Shalloch Mill.
,, insculpta (*Hall*) ..							×	Ardmillan.
,, llandeiloensis (*Dav.*)							×	Craighead, Ardmillan.
,, deltoidea (*Conrad.*)							×	Balclatchie conglomerate, Craighead, Dow Hill, Ardmillan.
		×						Woodland Point.
,, retroflexa (*Salter*)							×	Craighead, Dow Hill, Ardmillan, Balclatchie conglomerate.
,, corrugatella (*Dav.*)							×	Balclatchie, Benan Crag, Dow Hill, Ardmillan.
		×	×					Woodland Point, Newlands, Rough Neuk.
					×			Shalloch Mill.
,, expansa (*Sow.*) ..							×	Craighead, Minuntion, Doularg, Ardmillan.
				×				Auldthorns.
			×					Mulloch Hill, Rough Neuk, High Road.
,, grandis (*Sow.*) ..				×				Thraive Glen.
,, arenacea (*Salter*) ..	×							Camregan Wood.
		×						Woodland Point.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Strophomena Waltoni (*Dav.*)	×				•			Cuddystone Glen.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
,, sp.							×	Dow Hill, Ardmillan, Craighead.
,, sp.					×			Shalloch Mill.
Leptæna sericea (*Sow.*	×							Penkill, Camregan Wood.
			×					Mulloch Hill, Rough Neuk.
					×			Shalloch Mill.
				×				Starfish Bed, Auldthorns.
							×	Craighead, Minuntion, Balclatchie.
,, ,, var. rhombica (*M'Coy*)							×	Craighead, Balclatchie conglomerate.
,, transversalis (*Wahl.*)	×							Camregan Wood, Penkill, Bargany Pond Burn.
		×						Woodland Point, Newlands, Ptilograptus Bed.
				×				Auldthorns, Starfish Bed.
							×	Craighead, Balclatchie conglomerate.
,, quinquecostata (*M'Coy*)		×						Woodland Point.
					×			Shalloch Mill.
							×	Ardmillan, Balclatchie.
,, tenuicincta (*M'Coy*)					×			Shalloch Mill.
							×	Balclatchie, Ardmillan.
							×	Balclatchie conglomerate.
,, segmentum (*Angelin*)		×						Woodland Point.
	×							Cuddystone Glen.
					×			Shalloch Mill.
,, youngiana (*Dav.*)							×	Craighead, Balclatchie conglomerate.
,, Etheridgei (*Dav.*)							×	Craighead.
,, llandeiloensis (*Dav.*)							×	Craighead Ardmillan.
,, Grayii (*Dav.*)							×	Craighead.
,, scissa (*Salt.*)		×						Woodland Point.
							×	Balclatchie, Ardmillan.
LAMELLIBRANCHIATA.								
Ambonychia radiata (*Emmons*)							×	Ardmillan.
					×			Shalloch Mill.
,, orbicularis (*Conrad.*)			×				×	Craighead.
		×						Mulloch Hill, Rough Neuk.
								Woodland Point.
,, amygdalina (*Hall*)		×						Woodland Point.
,, bellistriata (*Hall*)	×						×	Craighead.
,, sp.								Penkill.
,, sp.	×						×	Ardmillan, Dow Hill.
Avicula elliptica (*Hall*)		×						Penkill.
,, sp.								Woodland Point.
,, sp.	×						×	Ardmillan.
Cardiola striata (*Sow.*)	×							Penkill.
,, sp.		×						Penkill.
,, fibrosa (*Sow.*)	×							Woodland Point.
Otenodonta astartæformis (*Salter*)								Penwhapple Glen.
,, varicosa (*Salter*)							×	Ardmillan, Dow Hill.
,, Eastnori (*Murch.*)							×	Ardmillan.
,, levata (*Hall*)				×				Thraive Glen.
,, sp.			×				×	Balclatchie.
Nucula subacuta (*M'Coy*)								Mulloch Hill, Rough Neuk.
Goniophora cymbæformis (*Sow.*)	×						×	Balclatchie.
		×						Penkill.
,, sp.								Woodland Point.
Mytilus semirugatus (*Portl.*)	×						×	Ardmillan.
,, gradatus (*Salter*)								Penkill, Bargany Pond Burn.
,, mytilimeris (*Conrad.*)					×			Shalloch Mill.
		×						Woodland Point.
	×							Penkill.
Lunulicardium elegans (*Salter*)	×							Penwhapple Glen.
Orthonota undata (*Sow.*)			×					Mulloch Hill, Rough Neuk, and in Wood.
		×						Newlands.
,, contracta (*Hall*)							×	Craighead.
,, prora (*Salter*)				×				Starfish Bed.
,, semisulcata (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, rigida (*Sow.*)	×							Camregan Wood.
,,	×							Penkill, Cuddystone Glen.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
LAMELLIBRANCHIATA—*contd.*								
Palæarca quadrata (*Salter*) ..				×				Mulloch Hill, Rough Neuk.
,, modiolaris (*Salter*) ..			×					Mulloch Hill, Rough Neuk.
Pterinea Sowerbyi (*M'Coy*) ..				×				Starfish Bed.
,, tenuistriata (*M'Coy*) ..	×							Camregan Wood.
Pleurorhynchus dipterus (*Salter*)							×	Craighead, Balclatchie conglomerate, Minuntion.
,, pristis (*Salt.*) ..			×					Mulloch Hill, Rough Neuk.
GASTEROPODA.								
Acroculia haliotis (*Sow.*)				×				Thraive Glen.
,, sp.			×					Mulloch Hill, High Road Quarries.
Bucania profunda (*Hall*)							×	Craighead.
,, sp.							×	Ardmillan, Balclatchie, Dow Hill.
,, sp.					×			Shalloch Mill.
Cyclonema carinatum					×			Shalloch Mill.
,, sp.	×							Cuddystone Glen, Penkill.
,, sp.					×			Shalloch Mill.
Cyrtolites euryomphalus (*Linds.*)? ..		×						Newlands.
,, orbiculus (*Linds.*)? ..							×	Balclatchie conglomerate.
,, sp.							×	Balclatchie, Craighead.
Enomphalus funatus (*Sow.*) ..					×			Shalloch Mill.
,, sp.					×			Whitehouse Bay.
,, granulatus (*Portl.*)			×					Mulloch Hill, Rough Neuk.
,, qualteriatus (*Schl.*)		×						Newlands.
,, sp.				×				Thraive Glen.
,, sp.			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
,, sp.	×							Cuddystone Glen, Penkill.
Fusispira elongata (*Hall*)? ..		×						Woodland Point.
,, sp.		×						Woodland Point.
Holopella obsoleta (*Sow.*) ..				×				Thraive Glen.
			×					Mulloch Hill, Rough Neuk.
,, sp.		×						Woodland Point.
,, tenuicincta (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
Holopea paludiniformis (*Hall*) ..							×	Craighead.
,, lymnæoides (*Forbes*) ..				×				Thraive Glen.
Loxonema elegans (*M'Coy*) ..				×				Thraive Glen.
Murchisonia obscura (*Portl.*) ..				×				Thraive Glen.
,, (Pleurotomaria) bicincta (*Hall*)					×			Shalloch Mill.
,, simplex (*M'Coy*) ..							×	Balclatchie.
,, cancellatula (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, sp.					×			Shalloch Mill.
,, sp.		×						Woodland Point.
Oriostoma discors (*Sow.*) ..		×						Woodland Point.
					×			Shalloch Mill.
,, angulatum (*Linds.*) ?			×					Mulloch Hill, Rough Neuk.
Ophileta nerine (*Billings*) ..					×			Shalloch Mill.
,, compacta (*Salter*) ..					×			Shalloch Mill.
				×				Threave Glen.
,, sp.							×	Craighead.
Pleurotomaria turrita (*Portlock*)				×				Thraive Glen.
,, alata (*Sow.*) ..		×						Woodland Point.
,, scutulata (*Linds.*)		×						Woodland Point.
,, trochiformis (*Portl.*) ..							×	Ardmillan.
,, claustrata (*Linds.*)			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.	×							Penkill, Bargany Pond Burn.
Platyceras cornutum (*Hisinger*)		×						Newlands.
	×							Camregan Wood.
,, sp.							×	Craighead.
Platyschisma helicites (*Sow.*) ..				×				Thraive Glen.
Raphistoma sp.							×	Ardmillan, Dow Hill, Balclatchie.
,, planistria, var. parva (*Hall*) ? ..				×				Thraive Glen.
,, æqualis (*Salter*)? ..							×	Balclatchie conglomerate.
Trochus Moorei (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
Trochonema sp.			×					Mulloch Hill, Rough Neuk.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
GASTEROPODA—*continued.*								
Metoptoma sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
Helminthochiton (Chelodes) Grayæ (*H. (Woodward)*				×				Thraive Glen.
,, sp.							×	Balclatchie.
,, sp.							×	Ardmillan, Dow Hill.
PTEROPODA?								
Conularia elongata (*Portl.*)							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
,, Sowerbyi (*Defrance*)							×	Craighead.
,, bilineata (*Linds.*)			×					Mulloch Hill, Rough Neuk.
,, subtilis (*Salter*)		×		×				Thraive Glen, Starfish Bed.
,, aspersa (*Linds.*)?		×						Woodland Point.
Hyolithes elegans (*Barr.*)				×				Woodland Point.
,, (Theca) operculatus (*Salter*)								Thraive Glen.
,, ,, triangularis (*Portl.*)							×	Balclatchie.
,, acutus (*Eichwald*)					×			Whitehouse Bay.
,, reversus (*Salt.*)				×				Thraive Glen.
,, sp.							×	Ardmillan.
,, sp.							×	Balclatchie.
,, sp.							×	Craighead.
,, sp.	×						×	Ardmillan.
,, sp.			×					Penkill.
Pterotheca corrugata (*Salter*)								Mulloch Hill, Rough Neuk.
,, transversa (*Salter*)							×	Balclatchie.
,, sp.							×	Ardmillan.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
,, sp	×							Penkill.
,, sp.					×			Shalloch Mill.
HETEROPODA.								
Eccultomphalus Bucklandi (*Portl.*)					×			Shalloch Mill.
,, lævis *Sow.*)							×	Ardmillan, Dow Hill, Craighead.
,, sp.					×			Shalloch Mill.
,, sp.		×					×	Craighead, Balclatchie.
Bellerophon wenlockensis (*Sow.*)			×					Woodland Point.
,, carinatus (*Sow.*)					×			Mulloch Hill, Rough Neuk.
,, dilatatus (*Sow.*)			×					Shalloch Mill.
,, sphæra (*Linds.*)?		×						Thraive Glen.
,, bilobatus (*Sow.*)								Mulloch Hill, Rough Neuk, Craigens Quarry, and in Wood.
,, trilobatus (*Sow.*)	×		×					Woodland Point.
,, expansus (*Sow.*)								Woodland Point.
,, punctifrons (*Emmons*)							×	Thraive Glen, Starfish Bed.
,, subdecussatus (*M'Coy*)							×	Ardmillan, Dow Hill, Balclatchie.
,, Urei (*Fleming*)								Thraive Glen.
,, squamosus (*Linds.*)			×				×	Ardmillan.
,, elongatus (*Portlock*)								Penkill.
,, Argo (*Billings*)?								Woodland Point.
,, sp.	×							Mulloch Hill, High Road.
sp.		×						Drummuck.
							×	Ardmillan, Balclatchie.
							×	Craighead.
			×					Mulloch Hill, Rough Neuk.
				×				Drummuck.
								Drummuck.
			×					Mulloch Hill.
				×				Thraive Glen.
								Thraive Glen.
					×			Shalloch Mill.
	×							Penkill.
		×						Newlands, Woodland Point.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
HETEROPODA—*continued.*								
Bellerophon sp.					×			Shalloch Mill.
,, sp.							×	Balclatchie conglomerate.
,, sp.							×	Craighead, Ardmillan, Balclatchie, Dow Hill.
Maclurea magna (*Lesueur*)							×	Aldons, Tramitchell, Minuntion.
,, matutina (*Hall*) ?							×	Balclatchie conglomerate.
,, Logani (*Salter*)							×	Craighead.
,, macromphala (*M'Coy*)							×	Craighead.
CEPHALOPODA.								
Orthoceras politum (*M'Coy*)						×		Pinmore, Waterfall Penwhapple Glen.
,, Avelini (*Salter*)							×	Ardmillan.
,, bilineatum (*Hall*)					×		×	Craighead.
,, arcuoliratum (*Hall*)					×			Shalloch Mill.
,, ludense (*Sow.*)					×			Shalloch Mill.
				×				Thraive Glen.
,, vagans (*Salter.*)					×			Shalloch Mill.
				×				Thraive Glen.
,, tenuicinctum (*Portl.*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
,, distans (*Sow.*)		×						Woodland Point.
				×				Starfish Bed.
,, imbricatum (*Wahl.*)			×					Mulloch Hill, Rough Neuk, High Road Quarry.
		×						Woodland Point.
	×							Penkill, Cuddystone Glen.
,, tracheale (*Sow.*)		×						Woodland Point.
,, mocktreense (*Sow.*)		×						Woodland Point.
,, bullatum (*Sow.*)					×			Whitehouse Bay.
		×						Woodland Point.
,, primævum (*Forbes*)	×							Penkill.
				×				Thraive Glen.
,, angulatum (*Wahl.*)			×					Mulloch Hill, Ptilograptus Bed.
		×						Woodland Point, Newlands.
	×							Penkill.
,, Bacchus (*Barr.*)	×							Penkill, Bargany Pond Burn.
	×							Penwhapple Glen, Penkill Beds.
,, annulatum (*Sow.*)	×							Penwhapple Glen.
,, Grindrodi (*Blake*)	×							Penkill Beds, Penwhapple Glen.
,, fusiforme (*Hall*) ?	×							Penkill, Penwhapple Glen.
,, multicinctum (*Hall*)	×							Penkill.
,, sp.	×							Camregan Wood.
,, gracile (*Portlock*)					×			Shalloch Mill.
,, subundulatum (*Portl.*)							×	Dow Hill.
,, sp.				×				Thraive Glen.
Phragmoceras arcuatum (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, sp.		×						Woodland Point.
,, sp.							×	Balclatchie conglomerate.
Endoceras proteiforme, var. strangulatum (*Hall*)				×			×	Thraive Glen. Balclatchie, Dow Hill.
Gomphoceras sp.	×							Penkill.
,, crater (*Blake*)		×						Woodland Point.
,, cinctum (*Blake*)	×							Camregan Wood.
Poterioceras sp.	×							Penkill.
Cyrtoceras victor (*Barr.*)?				×				Starfish Bed.
,, arcuatum (*Hall*)		×						Woodland Point.
,, sp.							×	Craighead.
,, sp.							×	Balclatchie conglomerate.
,, compressum (*Sow.*)	×							Penkill.
,, scoticum (*Blake*)							×	Craighead, Minuntion.
,, annulatum (*Hall*)			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Minuntion.
Oncoceras sp.			×					Mulloch Hill.
,, sp.		×						Woodland Point.
,, sp.		×						Newlands.
Trocholites planorbiformis (*Conrad*)							×	Craighead
,, cornuarietis (*Sow.*)			×					Mulloch Hill, Rough Neuk.
Trochoceras aspersum (*Barr.*)?		×						Woodland Point.

No. 4.—Complete List of Fossils from the Stinchar Limestone Series (Upper Llandeilo) of the Girvan District of the South of Scotland.

ALGÆ. (?)

Girvanella problematica (*Nich. & Eth.*)

RHIZOPODA?

Nidulites favus (*Salter*).

FORAMINIFERA.

Saccammina Carteri (*Brady*).

HYDROZOA.

Cryptograptus tricornis (*Carr.*)
Clathrograptus cuneiformis (*Lapw.*)
Climacograptus bicornis (*Hall*).
,, nanus.
,, Schärenbergi (*Lapw.*)
Dicellograptus sextans (*Hall*).
,, sp.
Dicranograptus ramosus (*Hall*).
,, sp.
Didymograptus superstes (*Lapw.*)
,, sp.
Diplograptus foliaceus (*Murch.*)
,, rugosus (*Emm.*)
,, sp.
Glossograptus Hincksi (*Hopk.*)

CŒLENTERATA.

ACTINOZOA.

Chætetes (*Fischer*).
Favosites girvanensis (*Nich. and Eth.*)
Fistulipora pilula (*Nich. and Eth.*)
Halysites sp.
Heliolites Grayi (*Edw. and Haime*).
Labechia canadensis (*N. and Murie*).
Lindströmia subduplicata (*M'Coy*).
Lyopora favosa (*M'Coy*).
Monticulipora girvanensis (*Nich.*)
Petraia elongata (*Phil.*)
Prasopora Grayæ (*Nich. and Eth.*)
Propora Edwardsi (*Nich. and Eth.*)
Stenopora fibrosa (*Goldf.*)
Streptelasma æquisulcatum (*M'Coy*).
,, aggregatum (*N. and E.*)
,, craigense (*M'Coy*).
,, europæum (*Rom.*)
Stylarœa occidentalis (*Nich. and Eth.*)
Tetradium Peachi (*Nich. and Eth.*)
Thecostegites scoticum (*Nich. and Eth.*)

CRINOIDEA.

Glyptocrinus (*Hall*) sp.

ANNELIDA.

Cornulites (*Schl.*) sp.
Serpulites longissimus (*Murch.*)

CIRRIPEDIA.

Turrilepas (*Woodw.*) sp.

OSTRACODA.

Cythere aldensis (*M'Coy*).
,, ,, var. major (*Jones*).
,, grayana (*Jones*).
,, wrightiana (*Jones and Holl.*)
Primitia barrandiana (*Jones*).

TRILOBITA.

Ampyx (*Dalm.*) sp.
Asaphus (Isotelus) gigas (*Dekay*).
,, ,, rectifrons (*Portl.*)
Bronteus (*Goldf.*) sp.
Calymene Blumenbachi (*Brong.*)
Cheirurus bimucronatus (*Murch.*)
,, gelasinosus (*Portl.*)
Dindymene (*Corda.*) sp.
Encrinurus punctatus (*Brün.*)
,, ,, var. arenaceus (*Salt.*)
,, ,, var. calcareus (*Salt.*)
Harpes (*Goldf.*) sp.
Illænus (Dysplanus) æmulus (*Salt.*)
,, ,, Bowmani (*Salt.*)
,, ,, latus (*M'Coy*).
,, Portlocki (*Salt.*)
,, sp.
Lichas hibernicus (*Portl.*)
Phacops Brongniarti (*Portl.*)
Remopleurides Barrandei (*Eth. & Nich.*)
,, Colbii (*Portl.*)
,, laterispinifer (*Portl.*)
,, sp.
Sphærexochus mirus (*Beyr.*)
Trinucleus (*Lhwyd*). sp.

BRACHIOPODA.

Acrotreta Nicholsoni (*Dav.*)
Crania siluriana (*Dav.*)
,, sp.
Discina perrugata (*M'Coy*).
Leptæna Etheridgei (*Dav.*)
,, Grayi (*Dav.*)
,, llandeiloensis (*Dav.*)
,, (Plectambonites) quinquecostata (*M'Coy*).

BRACHIOPODA—*continued.*

,, sericea (*Sow.*)
,, ,, var. rhombica (*M'Coy*).
,, (Christiania) tenuicincta (*M'Coy*).
,, (Plectambonites) transversalis (*Wahl.*)
,, youngiana (*Dav.*)
Lingula attenuata (*Sow.*)
,, granulata (*Phil.*)
,, ovata (*M'Coy*).
,, quadrata (*Eichw.*)
,, Ramsayi (*Salt.*)
Meristella angustifrons ? (*M'Coy*).
Nucleospira pisum (*Sow.*)
Orthis balcletchiensis (*Dav.*)
,, (Platystrophia) biforata (*Schl.*)
,, calligramma (*Dalm.*)
,, ,, var. virgata (*Salt.*)
,, ,, var. scotica (*Dav.*)
,, confinis (*Salt.*)
,, crispa (*M'Coy*).
,, (Dalmanella) elegantula (*Dalm.*)
,, (Dinorthis) flabellulum (*Sow.*)
,, girvanensis (*Dav*)
,, intercostata (*Portl.*)
,, protensa (*Sow.*)
,, sowerbyana (*Dav.*)
,, (Dalmanella) testudinaria (*Dalm.*)
,, turgida (*M'Coy*).
,, unguis (*Sow.*)
,, vespertilio (*Sow.*)
Rhynchonella æmula (*Salt.*)
,, balcletchiensis (*Dav.*)
,, Lapworthi (*Dav.*)
,, nasuta (*M'Coy*).
,, Peachi (*Dav.*)
,, (Hyattella) portlockiana (*Dav.*)
,, Salteri (*Dav.*)
,, scotica (*Dav.*)
,, sub-borealis (*Dav.*)
,, Thomsoni (*Dav.*)
,, Weaveri (*Salt.*)
Siphonotreta anglica (*Morris*).
,, micula (*M'Coy*).
,, scotica (*Dav.*)
Strophomena corrugatella (*Dav.*)
,, (Rafinesquina) deltoidea (*Conr.*)
,, (Rafinesquina) expansa (*Sow.*)
,, Grayi (*Dav.*)
,, imbrex (*Pand.*), var. semiglobosa (*Dav.*)
,, llandeiloensis (*Dav.*)
,, retroflexa (*Salt.*)
,, (Leptæna) rhomboidalis (*Wilck.*)
,, sp.

BRACHIOPODA—*continued.*

Triplesia Grayæ (*Dav.*)
,, sp.

LAMELLIBRANCHIATA.

Ambonychia amygdalina (*Hall*).
,, radiata (*Emm.*)
Orthonota contracta (*Hall*).
Pleurorhynchus dipterus (*Salt.*)

GASTEROPODA.

Bellerophon acutus (*Sow.*)
,, punctifrons (*Emm.*)
,, sp.
,, (Bucania) profunda (*Hall*).
Chelodes (*Dav. and King*).
,, (Helminthochiton) sp.
Cyrtolites (*Conrad*) sp.
Ecculiomphalus Bucklandi (*Portl.*)
,, lævis (*Sow.*)
,, sp.
Holopea paludiniformis (*Hall*).
Maclurea Logani (*Salt.*)
,, (Ophileta) macromphala (*M'Coy*).
,, Maccoyi (*Salt.*)
,, magna (*Lesu.*)
,, matutina (*Hall*).
Macrocheilus (*Phillips*) sp.
Metoptoma (*Phil.*) sp.
,, (Tryblidium) sp.
Murchisonia angulata (*Sow.*)
,, (Pleurotomaria) bicincta (*Hall*).
,, gracilis (*Hall*).
,, gyrogonia (*M'Coy*).
,, vitellia (*Bill.*)
Ophileta (*Vanux*) sp.
Pleurotomaria (*Defr.*)
,, (Raphistoma) lenticularis (*Sow.*)
,, qualteriata (*Schl.*)
Platyceras (*Conr.*) sp.

PTEROPODA. (?)

Conularia elongata (*Portl.*)
,, Sowerbyi (*Defr.*)
Hyolithes (*Eichw.*) sp.
Theca (*Sow.*) sp.

CEPHALOPODA.

Cyrtoceras inæquiseptum (*Portl.*)
,, multicamaratum (*Hall*).
,, scoticum (*Blake*).
,, sp.
Orthoceras bilineatum (*Hall*).
,, pendens (*Blake*).
,, politum (*M'Coy*).
,, sp.
Trocholites planorbiformis (*Conrad.*)

No. 5.—Comparative Table of Fossils from the Caradoc Rocks of Balclatchie, Leadhills, Wallace's Cast, Kilbucho, Glencotho, Wrae, and Winkston.

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
Rhizopoda?							
Cyclocrinus (*Eichwald*)							
,, sp.			×				
Nidulites (*Salter*)							
,, favus (*Salt.*)	×	×	×	×			
Spongida.							
Ischadites (*Murchison*)							
,, Kœnigi (*Nich. and Eth.*)	×						
Hydrozoa.							
Dicranograptus (*Hall*)							
,, tardiusculus (*Lapw.*) ...	×						
Dicellograptus (*Hopkinson*)							
,, moffatensis (*Carr.*)	×						
Diplograptus (*M'Coy*)							
,, rugosus (*Emm.*)...	×						
Climacograptus (*Hall*)							
,, Schärenbergi (*Lapw.*) ...	×						
Actinozoa.							
Alveolites (*Lamarck*)							
,, sp.			×				
Favosites (*Lamarck*)							
,, asper (*D'Orb.*)	×						
,, cristatus (*Blum.*)							×
,, gothlandicus (*Fougt*)				×			
,, sp.			×				
Fistulipora (*M'Coy*)							
,, favosa (*Nich. and Eth.*)	×						
Heliolites (*Dana*)							
,, sp.			×				
Lindströmia (*Nicholson and Thomson*)							
,, subduplicata (*M'Coy*)			×	×			
,, ,, var. crenulata (*M'Coy*) ...				×			
Lyopora (*Nicholson and Etheridge*)							
,, favosa (*M'Coy*)				×			
Monticulipora (*D'Orbigny*)							
,, lens (*M'Coy*)		×					
Palæocyclus (*Edwards and Haime*)							
,, sp.			×	×			

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
ACTINOZOA—*continued.*							
Petraia (*Münster*)							
,, bina (*Lonsd.*)		×	×	×			
,, elongata (*Phil.*)...		×					
,, uniserialis (*M'Coy*)		×		×			
,, zic-zac (*M'Coy*)...			×				
Stenopora (*Lonsdale*)							
,, (Favosites) fibrosa (*Goldf.*) ...			×	×			
Syringophyllum (*Edwards and Haime*)							
,, (Sarcinula) sp.			×				
Tetradium (*Dana*)							
,, sp.			×				
CRINOIDEA.							
Glyptocrinus (*Hall*)							
,, basalis (*M'Coy*)		×	×	×	×	×	×
,, sp....	×	×		×	×	×	×
Myelodactylus (*Hall*)							
,, sp.	×						
Crinoid stems.	×	×		×	×	×	×
ANNELIDA.							
Serpulites (*M'Leay*)							
,, longissimus (*Murch.*)			×				
Tentaculites (*Schlotheim*)							
,, sp.	×						
CIRRIPEDIA.							
Turrilepas (*Woodward*)							
,, scotica (*Nich. and Eth.*)	×						
,, sp.							×
PHYLLOCARIDA.							
Pinnocaris (*Etheridge, jnr.*)							
,, Lapworthi (*Eth., jnr.*)	×						
Peltocaris (*Salter*)							
,, (?) sp....	×						
TRILOBITA.							
Acidaspis (*Murchison*)							
,, Grayæ (*Eth., jnr.*)	×						
,, hystrix (*Wyv.-Thom.*)	×						
,, Lalage (*Wyv.-Thom.*)	×						
Agnostus (*Brongniart*)							
,, agnostiformis (*M'Coy*)	×						
Ampyx (*Dalman*)							
,, Hornei (*Eth. and Nich.*)	×						
,, Maccallumi (*Salt.*)	×						
,, mammilaris (*Sars*)	×						
,, rostratus (*Sars*)	×						
,, sp.	×						
Asaphus (*Bronguiart*)							
,, (Isotelus) gigas (*Dekay*)	×						
,, ,, rectifrons (*Portl.*) ...	×						
,, sp.					×		

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotcho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
TRILOBITA—*continued.*							
Barrandia (*M'Coy*)							
,, sp.	×						
Bronteopsis (*Wyville-Thomson*)							
,, scotica (*Salt.*)	×						
Bronteus (*Goldfuss*)							
,, Andersoni (*Eth. and Nich.*) ...	×						
Calymene (*Brongniart*)							
,, sp.		×					
Cheirurus (*Beyrich*)							
,, bimucronatus (*Murch.*)	×						×
,, clavifrons (*Dalm.*)				×			
,, gelasinosus (*Portl.*)	×						×
,, Sedgwicki (*M'Coy*)	×						
,, sp.	×	×				×	×
Cybele (*Lovén*)							
,, verrucosa (*Dalm.*)	×						
,, sp.	×						
Deiphon (*Barrande*)							
,, Forbesi (*Barr.*)	×						
Harpes (*Goldfuss*)							
,, parvulus (*M'Coy*)						×	
,, sp.	×						
Homalonotus ? (*Kœnig*)							
,, sp....		×					
Illænus (*Dalman*)							
,, (Dysplanus) Bowmani (*Salt.*) ...	×					×	×
,, Davisi, var. B. involutus (*Salt.*) ...						×	
,, (Dysplanus) latus ? (*M'Coy*) ...			×				
,, ,, Thomsoni (*Salt.*) ...	×						
,, young of...					×		
,, sp.	×						
Lichas (*Dalman*)							
,, Grayi (*Fletch.*)	×						
,, hibernicus (*Portl.*)	×						
,, sp.	×						
Ogygia (*Brongniart*)							
,, sp.		×					
Phacops (*Emmrich*)							
,, (Acaste) alifrons (*Salt.*)				×			
,, ,, Brongniarti (*Portl.*) ...	×		×	×			
,, (Dalmanites) caudatus ? (*Brünn.*) ...		×		×			
Proetus (*Steininger*)							
,, girvanensis (*Eth. and Nich.*)... ...	×						
Remopleurides (*Portlock*)							
,, Barrandei (*Eth. and Nich.*) ...	×						
,, Colbii (*Portl.*)			×				
,, laterispinifer (*Portl.*)... ...	×		×				
,, nov. sp.			×				
Salteria (*Wyville-Thomson*)							
,, primeva (*Wyv.-Thom.*)	×						
Sphærexochus (*Beyrich*)							
,, mirus (*Beyr.*)	×				×	×	×
Staurocephalus (*Barrande*							
,, globiceps (*Portl.*)	×						

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
TRILOBITA—*continued.*							
Staurocephalus unicus (*Wyv.-Thom.*) ...	×						
Stygina (*Salter*)							
,, latifrons (*Portl.*)	×						
Trinucleus (*Lhywd*)							
,, concentricus (*Eaton*)	×						
,, fimbriatus (*Murch.*)		×					
,, Macconochiei (*Eth. and Nich.*) ...	×						
,, ornatus (*Sternb.*)	×						
,, sp.				×			
POLYZOA.							
Ceriopora (*Goldfuss*)							
,, oculata (*Goldf.*)				×			
Fenestella (*Lonsdale*)							
,, sp.		×					
Ptilodictya (*Lonsdale*)							
,, costellata (*M'Coy*)				×			
,, dichotoma (*Portl.*)...	×	×	×				
,, sp.			×				
Retepora (*Lamarck*)							
,, sp.	×		×				
Sulcoretepora (*D'Orbigny*)							
,, sp.			×				
BRACHIOPODA.							
Acrotreta (*Kutorga*)							
,, costata ? (*Dav.*)	×						
,, Nicholsoni (*Dav.*)	×						
Crania (*Retzius*)							
,, sp.	×						
Discina (*Lamarck*)							
,, oblongata (*Portl.*)	×						
,, perrugata (*M'Coy*)	×					×	×
,, sp.					×	×	
Leptæna (*Dalman*)							
,, (Plectambonites) quinquecostata (*M'Coy*)	×						×
,, scissa = llandeiloensis (*Dav.*) ...	×			×			
,, sericea (*Sow.*)	×	×	×	×	×		×
,, ,, var. rhombica (*M'Coy*) ...	×	×	×				
,, (Christiania) tenuicincta (*M'Coy*) ...	×	×	×	×			
,, (Plectambonites) transversalis (*Wahl.*)			×	×		×	×
,, youngiana (*Dav.*)	×						
,, sp.					×		
Lingula (*Bruguière*)							
,, attenuata (*Sow.*)	×		×		×	×	×
,, brevis (*Portl.*)	×						
,, canadensis (*Bill.*)	×						
,, granulata (*Phil.*)	×						
,, longissima (*Pand.*)						×	
,, ovata (*M'Coy*)	×						
,, Ramsayi (*Salt.*)	×						×
Meristella (*Hall*)							
,, (Whitfieldia) tumida (*Dal.*) ...					×		×

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
BRACHIOPODA—*continued.*							
Meristina (*Hall*)							
,, (= Whitfieldia (*Sow.*)							
,, (Meristella) tumida (*Dalm.*) ...					×		×
Obolella or Kutorgina (*Billings*)							
,, sp.							×
Orthis (*Dalman*)							
,, Actoniæ (*Sow.*)					×	×	×
,, (Platystrophia) biforata (*Schl.*) ...		×			×		
,, (Bilobites) biloba (*Linn.*)							
,, Bouchardi, var. balcletchiensis (*Dav.*)	×						
,, calligramma (*Dalm.*)		×	×	×	×	×	×
,, ,, var. plicata (*Sow.*) ...	×						
,, ,, var. virgata (*Salt.*) ...	×						
,, Carausii (*Salt.*)	×						
,, crispa (*M'Coy*)	×	×	×	×			
,, (Dalmanella) elegantula (*Dalm.*) ...	×		×				
,, (Dinorthis) flabellulum (*Sow.*)				×			
,, girvanensis ? (*Dav.*)	×						×
,, Lapworthi (*Dav.*)	×						
,, polygramma (*Sow.*)							
,, ,, var. pentlandica (*Dav.*) ...	×	×					
,, protensa (*Sow.*)				×			
,, Rankini (*Dav.*)	×						
,, rustica (*Sow.*)				×			
,, sowerbyana (*Dav.*)	×				×	×	×
,, (Dalmanella) testudinaria (*Dalm.*) ...	×	×	×				
,, turgida (*M'Coy*)	×						
,, unguis (*Sow.*)				×			
,, vespertilio (*Sow.*)			×				
,, sp.			×				×
Paterula (*Davidson*)							
,, (Discina) balcletchiensis (*Dav.*) ...	×						
Porambonites (*Pander*)							
,, intercedens (*Pand.*)					×		
,, sp.					×		
Rhynchonella (*Fischer*)							
,, ardmillanensis (*Dav.*)	×						
,, balcletchiensis (*Dav.*)	×						
,, borealis (*Schl.*)			×				
,, cuneatella (*Dav.*)	×						
,, girvanensis (*Dav.*)	×						
,, Jacki (*Dav.*)		×					
,, maccoyana (*Dav.*)					×		
,, nasuta (*M'Coy*)	×						
,, nucula (*Sow.*)	×						
,, Stricklandi (*Sow.*)			×				
,, sp.	×		×				
Siphonotreta (*De Verneuil*)							
,, micula (*M'Coy*)							×
Stricklandinia (*Billings*)							
,, balcletchiensis (*Dav.*)	×						
trophomena (*Rafinesque*)							
,, arenacea (*Salt.*)		×					
,, compressa (*Sow.*)	×						

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
BRACHIOPODA—*continued.*							
Strophomena corrugatella (*Dav.*)	×	×	×				
,, (Rafinesquina) deltoidea (*Conr.*)	×						×
,, ,, var. rotundata (*Conr.*) ...			×				
,, ,, var. expansa (*Sow.*) ...	×	×					
,, grandis (*Sow.*)		×	×				
,, imbrex (*Pand.*)	×						
,, (Orthis) kilbuchoensis (*Dav.*) ...	×		×	×			
,, llandeiloensis (*Dav.*)	×						
,, retroflexa (*Salt.*)...	×						
,, (Leptæna) rhomboidalis (*Wilck.*)	×		×	×			
,, semiglobosina (*Dav.*)	×						
,, shallockiensis (*Dav.*)	×						
,, sp.	×			×			×
Triplesia (*Hall*)							
,, spiriferoides ? (*M'Coy*)	×						
,, sp.							×
LAMELLIBRANCHIATA.							
Ambonychia (*Hall*)							
,, radiata (*Emmons*)	×						
,, sp.	×						
Arca (*Linnæus*)							
,, edmondiæformis (*M'Coy*)	×						
Avicula (*Klein*)							
,, sp.	×						
Ctenodonta (*Salter*)							
,, anglica (*D'Orb.*)	×						
,, astarteformis (*Salt.*)	×						
,, levata (*Hall*)	×		×				
,, (Nucula) subacuta (*M'Coy*) ...	×						
,, varicosa (*Salt*)	×						
,, sp.	×	×	×				
Cucullella (*M'Coy*)							
,, sp.			×				
Goniophora (*Phillips*)							
,, sp.	×						
Modiolopsis (*Hall*)							
,, modiolaris (*Conrad*)	×						
,, orbicularis (*Sow.*)...			×	×			
,, sp.		×	×				
Orthonota (*Conrad*)							
,, undata ? (*Sow.*)					×		
Pleurorhynchus (*Phillips*)							
,, (Conocardium) dipterus (*Salt.*)	×						
GASTEROPODA.							
Bellerophon (*Montfort*)...							
,, acutus (*Sow.*)	×	×	×				
,, bilobatus (*Sow.*)	×						
,, dilatatus (*Sow.*)			×				
,, expansus (*Sow.*)	×						
,, trilobatus (*Sow.*)	×	×					

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
GASTEROPODA—*continued.*							
Bellerophon sp.	×		×				
,, (Bucania) sp.	×						
Chelodes (*Davidson and King*)							
,, (Helminthochiton) sp.	×		×				
Cyrtolites (*Conrad*)							
,, (Ecculiomphalus) orbiculus (*Lindst.*)	×						
,, sp.	×						
Cyclonema (*Hall*)							
,, crebristria (*M'Coy*)	×						
,, sp.		×			×	×	
Ecculiomphalus (*Portlock*)							
,, Bucklandi (*Portl.*)	×						
,, lævis (*Sow.*)	×						
,, minor (*Portl.*)...	×						
,, scoticus (*M'Coy*)	×						
,, sp.				×			
Euomphalus (*Sowerby*)							
,, (Bellerophon) sculptus (*Sow.*) ...			×		×		
,, sp.		×					
Holopea (*Hall*)							
,, concinna (*M'Coy*)			×		×		
Holopella (*M'Coy*)							
,, sp.		×					
Loxonema (*Phillips*)							
,, sp.			×		×		
Maclurea (*Lesueur*)							
,, (Opheileta) macromphala (*M'Coy*)...			×				
,, matutina (*Hall*)	×						
Macrochilina (*Bayle*)							
,, sp.			×				
Murchisonia (*De Verneuil et D'Archiac*)							
,, angulata (*Sow.*)				×			
,, gyrogonia (*M'Coy*)	×		×				
,, simplex (*M'Coy*)...	×						
,, sp.		×	×	×			
Ophileta (*Vanuxem*)							
,, compacta (*Salt.*)	×						
Pleurotomaria (*Defrance*)							
,, alata (*Wahl.*)			×				
,, elliptica (*His.*)		×	×	×			
,, (Raphistoma) lenticularis (*Sow.*)		×	×	×			
,, trochiformis (*Portl.*)	×						
,, sp.	×	×	×				
Raphistoma (*Hall*)							
,, æqualis (*Salt.*)	×						
,, sp.	×						
Turbo (*Linnæus*)							
,, sp.		×					
PTEROPODA ?							
Conularia (*Miller*)							
,, elongata (*Portl.*)	×		×				
,, sp.				×			

	Balclatchie.	Leadhills.	Wallace's Cast.	Glencotho.	Kilbucho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
PTEROPODA ?—*continued.*							
Hyolithes (*Eichwald*)							
,, (Theca) acutus (*Eichw.*)	×						
,, operculatus (*Salt.*)	×						
,, reversus (*Salt.*)	×						
,, triangularis (*Portl.*)	×						
,, sp.		×	×	×			
Pterotheca (*Salter*)							
,, corrugata (*Salt.*)	×		×				
,, transversa (*Salt.*)	×						
Cyrtoceras (*Goldfuss*)							
,, scoticum (*Blake*)			×			×	
,, sp.	×						
Endoceras (*Hall*)							
,, strangulatum (*Hall*)	×						
,, sp.			×				
Lituites (*Breynius*)							
,, (Nautilus) sp.			×				
Orthoceras (*Breynius*)							
,, arcuoliratum (*Hall*)			×			×	
,, Avelini (*Salt.*)	×		×				
,, pendens (*Blake*)			×		×		
,, politum (*M'Coy*)	×						
,, subundulatum (*Portl.*)	×						
,, sp.		×	×	×			
Phragmoceras (*Broderip*)							
,, sp.	×						
Trocholites (*Conrad*)							
,, (Lituites) cornu-arietis (*Sow.*) ...					×		
,, ,, sp.	×						

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
GASTEROPODA—*continued.*							
Bellerophon sp.	×		×				
,, (Bucania) sp.	×						
Chelodes (*Davidson and King*)							
,, (Helminthochiton) sp.	×		×				
Cyrtolites (*Conrad*)							
,, (Ecculiomphalus) orbiculus (*Lindst.*)	×						
,, sp.	×						
Cyclonema (*Hall*)							
,, crebristria (*M'Coy*)	×						
,, sp.		×			×	×	
Ecculiomphalus (*Portlock*)							
,, Bucklandi (*Portl.*)	×						
,, lævis (*Sow.*)	×						
,, minor (*Portl.*)	×						
,, scoticus (*M'Coy*)	×						
,, sp.				×			
Euomphalus (*Sowerby*)							
,, (Bellerophon) sculptus (*Sow.*) ...			×		×		
,, sp.		×					
Holopea (*Hall*)							
,, concinna (*M'Coy*)			×		×		
Holopella (*M'Coy*)							
,, sp.		×					
Loxonema (*Phillips*)							
,, sp.			×		×		
Maclurea (*Lesueur*)							
,, (Opheileta) macromphala (*M'Coy*) ...			×				
,, matutina (*Hall*)	×						
Macrochilina (*Bayle*)							
,, sp.			×				
Murchisonia (*De Verneuil et D'Archiac*)							
,, angulata (*Sow.*)				×			
,, gyrogonia (*M'Coy*)	×		×				
,, simplex (*M'Coy*)	×						
,, sp.		×	×	×			
Ophileta (*Vanuxem*)							
,, compacta (*Salt.*)	×						
Pleurotomaria (*Defrance*)							
,, alata (*Wahl.*)			×				
,, elliptica (*His.*)		×	×	×			
,, (Raphistoma) lenticularis (*Sow.*)		×	×	×			
,, trochiformis (*Portl.*)	×						
,, sp.	×	×	×				
Raphistoma (*Hall*)							
,, æqualis (*Salt.*)	×						
,, sp.	×						
Turbo (*Linnæus*)							
,, sp.		×					
PTEROPODA ?							
Conularia (*Miller*)							
,, elongata (*Portl.*)	×		×				
,, sp.				×			

	Balclatchie.	Leadhills.	Wallace's Cast.	Glencotho.	Kilbucho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
PTEROPODA ?—*continued.*							
Hyolithes (*Eichwald*)							
,, (Theca) acutus (*Eichw.*)	×						
,, operculatus (*Salt.*)	×						
,, reversus (*Salt.*)	×						
,, triangularis (*Portl.*)	×						
,, sp.		×	×	×			
Pterotheca (*Salter*)							
,, corrugata (*Salt.*)	×		×				
,, transversa (*Salt.*)	×						
Cyrtoceras (*Goldfuss*)							
,, scoticum (*Blake*)			×			×	
,, sp.	×						
Endoceras (*Hall*)							
,, strangulatum (*Hall*)	×						
,, sp.			×				
Lituites (*Breynius*)							
,, (Nautilus) sp.			×				
Orthoceras (*Breynius*)							
,, arcuoliratum (*Hall*)			×			×	
,, Avelini (*Salt.*)	×		×				
,, pendens (*Blake*)			×		×		
,, politum (*M'Coy*)	×						
,, subundulatum (*Portl.*)	×						
,, sp.		×	×	×			
Phragmoceras (*Broderip*)							
,, sp.	×						
Trocholites (*Conrad*)							
,, (Lituites) cornu-arietis (*Sow.*) ...					×		
,, ,, sp.	×						

No. 6.—Comparative Table of Fossils from the Wenlock-Ludlow Rocks of the South of Scotland.

	Pentlands.	Hagshaws.	Lesmahagow.	Kirkcudbright, Riccarton, &c.	Straiton.
Plantæ.					
Land plants				×	
Spongida.					
Amphispongia (*Salter*)					
,, oblonga (*Salt.*)	×				
Plectoderma (*Hinde*)					
,, scitulum (*Hinde*)	×				
Protospongia (*Salter*)				×	
Sponge	×				
Ischadites (*Murchison*)					
,, Kœnigi (*Murch.*)	×				
Hydrozoa.					
Cyrtograptus (*Carruthers*)					
,, Carruthersi (*Lapw.*)	?			×	
,, Murchisoni (*Carr.*)				×	
,, scoticus (*Lapw.*, M.S.)	×				
Monograptus (*Geinitz*)					
,, colonus (*Barr.*)	×			×	
,, Flemingi (*Salt.*) = priodon (*Bronn.*). ...	×			×	
,, galaensis (*Lapw.*)				×	
,, ludensis (*Murch.*) = priodon (*Bronn.*) ...				×	
,, priodon (*Bronn.*)	×			×	
,, riccartonensis (*Lapw.*)				×	
,, vomerinus (*Nich.*)	×			×	×
,, sp.	×	×		×	
Retiolites (*Barrande*)					
,, geinitzianus (*Barr.*)	×			×	×
Dictyonema (*Hall*)					
,, (Fenestella) assimile (*Lonsd.*)	×				
,, (Gorgonia) regulare (*Portl.*)	×				
,, retiforme (*Hall*)	×				
,, (Chondrites) verisimile (*Salt.*)	×				
,, sp.				×	
Actinozoa.					
Alveolites (*Lamarck*)					
,, repens (*Fougt*)	×				
,, sp.	×				
Favosites (*Lamarck*)					
,, alveolaris (*Goldf.*), asper (*D'Orb.*)	×	×			
,, gothlandicus (*Fougt*)	×				

	Pentlands.	Haghawa.	Leamahagow.	Kirkcudbright, Riccarton, &c.	Struiton.
ACTINOZOA—*continued.*					
Favosites multipora (*Lonsd.*)	×				
,, sp.	×				×
Heliolites (*Dana*)					
,, interstinctus (*Linn.*)	×				
,, sp.	×			×	×
Lindströmia (*Nich. and Thom.*)					
,, sp.		×			
Monticulipora (*D'Orbigny*)					
,, (Chætetes) Fletcheri (*M. Edw.*)... ...	×				
Petraia (*Münster*)					
,, bina (*Lonsd.*)	×			×	
,, (Streptelasma) elongata (*Phil.*)	×			×	
,, ,, subduplicata (*M'Coy*)	×				
,, uniserialis (*M'Coy*)	×				
,, sp.	×				
Ptychophyllum (*Milne Edwards*)					
,, (Strombodes) patellatum (*Schloth.*) ...	×				
Stenopora (*Lonsdale*)					
,, (Favosites) fibrosa (*Goldf.*)	×			?	
Syringopora (*Goldfuss*)					
,, sp.				×	
OPHIUROIDEA.					
Protaster (*Forbes*)					
,, Sedgwicki (*Forbes*)	×				
,, sp.	×				
Palæaster (*Hall*)					
,, sp.	×				
Palasterina (*M'Coy*)					
,, sp.	×				
ECHINOIDEA.					
Perischoechinus (*M'Coy*)					
,, sp.	×				
CRINOIDEA.					
Periechocrinus (*Austin*)					
,, sp.	×				
Crinoid stems	×	×		×	
ANNELIDA.					
Cornulites (*Schlotheim*)					
,, sp.	×	×		×	×
Serpulites (*M'Leay*)					
,, longissimus (*Murch.*)	×				
,, sp.	×				
Spirorbis (*Lamarck*)					
,, Lewisi (*Sow.*)	×		×		
CIRRIPEDIA.					
Anatifopsis (*Brady*)					
,, sp.	×				
Turrilepas (*Woodward*)					
,, Haswelli (*Edgell*, M.S.)	×				
,, Wrighti (*Woodw.*)	×				
,, sp.	×				

	Pentlands.	Haqshaws.	Leemahagow.	Kirkcudbright, Ricearton, &c.	Stralton.
OSTRACODA.					
Beyrichia (*M'Coy*)					
,, (Entomis) impendens (*Jones*)	×	×			×
,, Klœdeni (*M'Coy*)	×		×		×
,, ,, var.		×			
,, (Entomis) tuberosa (*Jones*)	×	×			
,, sp.	×	×			
Cythere (*Müller*)					
,, umbilicata (*Jones*)...	×				
Entomis (*M'Coy*)					
,, sp.	×	×			
PHYLLOCARIDA.					
Aptychopsis (*Barrande*)					
,, oblata (*Jones*)...				×	
,, ovota (*Jones*)				×	
,, Wilsoni (*Woodw.*)				×	
,, sp.				×	
Ceratiocaris (*M'Coy*)					
,, angusta (*Jones and Woodw.*)			×		
,, inequalis (*Barr.*)				×	
,, inornata (*M'Coy*)				×	
,, laxa (*Jones and Woodw.*)			×		
,, ludensis (*Woodw.*)				×	
,, Murchisoni (*M'Coy*)...			×		
,, papilio (*Salt.*)...		×		×	
,, patula (*Jones and Woodw.*)...			×		
,, robusta (*Salt.*)			×		
,, stygia (*Salt.*)			×		
,, tyrannus (*Salt.*)			×		
,, sp.	×	×	×	×	
Discinocaris (*Woodward*)					
,, sp.				×	
Peltocaris (*Salter*)					
,, aptychoides (*Salt.*)				×	
TRILOBITA.					
Acidaspis (*Murchison*)					
,, Brighti (*Murch.*)	×				
,, sp.	×				×
Calymene (*Brongniart*)					
,, Blumenbachi (*Brong.*)	×	×			×
,, sp.	×				
Cheirurus (*Beyrich*)					
,, bimucronatus (*Murch.*)	×				
Encrinurus (*Emmrich*)					
,, punctatus (*Brün.*)	×				×
,, ,, var. arenaceus (*Salt.*)					×
,, sp.	×	×			
Illœnus (*Dalman*)					
,, sp.		×			
Phacops (*Emmrich*)					
,, caudatus ? (*Brünn.*)				×	
,, Downingiæ (*Murch.*)	×				×
,, Stokesi (*M. Edw.*)	×				×
,, sp.	×	×			

	Pentlands.	Hagshaws.	Lesmahagow.	Kirkcudbright, Riccarton, &c.	Straiton.
TRILOBITA—*continued.*					
Proetus (*Steininger*)					
,, Stokesi (*Murch.*)		×			×
Trinucleus (*Lhwyd*)					
,, (?) Benniei (*Eth., jnr.*)				×	
XIPHOSURA.					
Neolimulus (*Woodward*)					
,, falcatus (*Woodw.*)			×		
EURYPTERIDA.					
Bembycosoma (*Laurie*)					
,, pomphicus (*Laurie*)	×				
Drepanopterus (*Laurie*)					
,, bembycoides (*Laurie*)	×				
,, lobatus (*Laurie*)...	×				
,, pentlandicus (*Laurie*)	×				
Eurypterus (*Dekay*)					
,, conicus (*Laurie*)	×				
,, cyclophthalmus (*Laurie*)	×				
,, lanceolatus (*Salt.*)			×		
,, minor (*Laurie*)	×				
,, obesus (*Woodw.*)			×		
,, punctatus ? (*Salt.*)				×	
,, scorpioides (*Woodw.*)...	×		×		
,, scoticus (*Laurie*)	×				
,, dolichoscelus (*Laurie*)			×		
,, sp.				×	×
,, sp.	×				
,, sp.	×				
Pterygotus (*Agassiz*)					
,, bilobus (*Salt.*)	×		×		
,, ,, var. accidens (*Woodw.*)			×		
,, ,, var. inornatus (*Woodw.*)			×		
,, ,, var. perornatus (*Salt.*)			×		
,, raniceps (*Woodw.*)			×		
Slimonia (*Page*)					
,, acuminata (*Salt.*)	×	×	×	×	
,, dubia (*Laurie*)	×				
Stylonurus (*Page*)					
,, elegans (*Laurie*)	×				
,, Logani (*Woodw.*)			×		
,, macrophthalmus (*Laurie*)	×				
,, ornatus (*Laurie*)	×		×		
ARACHNIDA.					
Palæophonus (*Thorell and Lindström*)					
,, caledonicus (*Hunter*)		×	×		
,, loudonensis (*Laurie*)	×				
MYRIAPODA.					
Archidesmus (*Peach*)					
,, loganensis (*Peach*)			×		
,, sp.		×	×		

	Pentlands.	Hagshaws.	Lesmahagow.	Kirkcudbright, Riccarton, &c.	Straiton.
POLYZOA.					
Ceriopora (*Goldfuss*)					
,, granulosa (*Goldf.*)	×				
,, sp.	×	×			
Diastopora (*Lamouroux*)					
,, irregularis (*Lonsd.*)	×				
,, sp.	×				
Glauconome (*Lonsdale*)					
,, disticha (*Goldf.*)	×				
,, sp.	×	×	×		
Ptilodictya (*Lonsdale*)					
,, dichotoma (*Portl.*)	×				
,, fucoides (*M'Coy*)	×				
,, lanceolata (*Goldf.*)					×
,, (Fenestella) scalpellum (*Lonsd.*)	×				
,, sp.	×			×	
BRACHIOPODA.					
Athyris (*M'Coy*)					
,, (Glassia) compressa (*Sow.*)	×	×			
,, sp.				×	
Atrypa (*Dalman*)					
,, (Leptocœlia) hemispherica (*Sow.*)				×	
,, reticularis (*Linn.*)	×				×
,, sp....	×				
Chonetes (*Fischer*)					
,, striatella (*Dalm.*)	×				
,, sp.	×				
Crania (*Retzius*)					
,, (Pholidops) implicata (*Sow.*)	×				
Cyrtia (*Dalman*)					
,, (Spirifera) exporrecta (*Wahl.*)	×				
Discina (*Lamarck*)					
,, rugata (*Sow.*)	×				
,, striata (*Sow.*)	×				
Glassia (*Davidson*)					
,, (Athyris) compressa (*Sow.*)	×				
,, obovata (*Sow.*)	×				
Leptæna (*Dalman*)					
,, sericea (*Sow.*)	×			?	
,, (Plectambonites) transversalis (*Wahl.*) ...	×			?	×
,, sp.	×				
Lingula (*Bruguière*)					
,, lata (*Sow.*)	×				
,, Lewisi (*Sow.*)	×				
,, minima (*Sow.*)			×		
,, Symondsi (*Salt.*)	×				×
,, sp.	×			×	
Meristella (*Hall*)					
,, MacLareni (*Hasw.*)	×				
,, (Whitfieldia) tumida (*Dalm.*)	×				
Nucleospira (*Hall*)					
,, pisum (*Sow.*)	×				
,, sp.	×				
Orbiculoidea (*D'Orbigny*)					
,, Forbesi (*Dav.*)	×				
,, var.	×				

	Pentlands.	Hagshaws.	Lesmahagow.	Kirkcudbright, Riccarton, &c.	Straiton.
BRACHIOPODA—*continued.*					
Orthis (*Dalman*)					
,, basalis (*Dalm.*)	×				
,, biforata (*Schl.*)					×
,, (Bilobites) biloba (*Linn.*)	×			×	
,, Bouchardi (*Dav.*)		×		×	×
,, calligramma (*Dalm.*)				×	
,, (Dalmanella) elegantula (*Dalm.*)	×	×			×
,, ,, var.	×				
,, (Dinorthis) flabellulum (*Sow.*)				×	×
,, (Skenidium) Lewisi (*Dav.*)	×				
,, minuta (*Haswell*) (young of Strophomena pecten)	×				
,, polygramma (*Sow.*)	×	×		×	
,, reversa (*Salt.*)	×			×	
,, rustica (*Sow.*)					×
,, sp.	×	×		×	×
Pholidops (*Hall*)					
,, (Crania) implicata (*Sow.*)	×				
Retzia (*King*)					
,, Barrandei (*Dav.*)					×
Rhynchonella (*Fischer*)					
,, borealis (*Schl.*)	×				
,, diodonta (*Dalm.*) (=Orthis borealis) ...				×	
,, nucula (*Sow.*)	×				
,, pentlandica (*Hasw.*)	×				
,, Wilsoni (*Sow.*)	×				
,, sp.		×		×	
Siphonotreta (*De Verneuil*)					
,, anglica (*Morris*)					×
Spirifera (*Sowerby*)					
,, crispa (*His.*)	×				
,, sulcata (*His.*)					×
Strophomena (*Rafinesque*)					
,, antiquata (*Sow.*)	×				
,, applanata (*Salt.*)	×				
,, compressa (*Sow.*)	×				
,, Hendersoni (*Dav.*)	×				
,, imbrex (*Pander*)	×				
,, pecten (*Linn.*)	×				
,, (Leptæna) rhomboidalis (*Wilck.*) ...	×	×			
,, Walmstedti (*Linds.*)	×				
,, sp.	×			×	
LAMELLIBRANCHIATA.					
Ambonychia (*Hall*)					
,, Hendersoni (*Eth. jnr.*)	×				
Anodontopsis (*M'Coy*)					
,, bulla (*M'Coy*)	×		×		
,, lucina (*Salt.*)	×		×		
,, Salteri (*Eth. jnr.*)	×				
,, sp.	×				
Cardiola (*Broderip*)					
,, fibrosa (*Sow.*)	×				
,, interrupta (*Brod.*)				×	
,, sp.	×				
Ctenodonta (*Salter*)					
,, obesa (*Salt.*)	×		×		

	Pentlands.	Hagshaws.	Leemahagow.	Kirkcudbright, Riccarton, &c.	Straiton.
LAMELLIBRANCHIATA—*continued.*					
Ctenodonta pentlandica (*Eth. jnr.*)	×				
,, quadrata (*M'Coy*)	×				
,, (Orthonota) thracioides (*Salt.*)	×				
,, sp.	×	×		×	×
Cucullella (*M'Coy*)					
,, antiqua (*Sow.*)	×				
,, sp.	×			×	
Goniophora (*Phillips*)					
,, cymbæformis (*Sow.*)	×			×	
Lunulicardium (*Münster*)					
,, elegans (*Salt.*)	×				
Modiolopsis (*Hall*)					
,, (Mytilus) chemungensis (*Conr.*)	×				
,, complanata (*Sow.*)			×		
,, Nilssoni (*His.*)			×		
,, platyphyllus (*Salt.*)	×				
,, sp.	×				×
Mytilus (*Linnæus*)					
,, mytilimeris (*Conr.*)	×		×		
Orthonota (*Conrad*)					
,, amygdalina (*Sow.*)	×		×		
,, ,, var. gentilis (*Salt.*)	×				
,, bulla (*Salt.*)	×				
,, decipiens (*M'Coy*)				×	
,, impressa (*Sow.*)	×		×		
,, rigida (*Sow.*)	×				
,, rotundata (*Sow.*)	×		×		
,, Salteri (*Eth. jnr.*)	×				
,, solenoides (*Sow.*)	×		×		
,, (Ctenodonta) thracioides (*Salt.*)	×				
,, truncata (*M'Coy*)	×				×
,, sp.	×	×	×		×
Pterinea (*Goldfuss*)					
,, asperula (*M'Coy*)	×				
,, pleuroptera (*Conr.*)			×		×
,, retroflexa (*Wahl.*)	×		×		
,, ,, var. squamosa (*M'Coy*)	×				
,, sowerbyana (*M'Coy*)	×				
,, tenuistriata (*M'Coy*)	×				
,, sp.				×	
Tellinomya (*Hall*)					
,, (Ctenodonta) sp.	×				
GASTEROPODA.					
Acroculia (*Phillips*)					
,, (Platyceras) antiquata (*Salter*)	×				
,, sp.	×				
Bellerophon (*Montfort*)					
,, acutus (*Sow.*)...				?	
,, carinatus (*Sow.*)	×				
,, dilatatus (*Sow.*)	×				
,, expansus (*Sow.*)	×				
,, sphæra (*Lindst.*)	×				
,, trilobatus (*Sow.*)				×	
Cyrtolites (*Conrad*)					
nov. sp.	×				

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
LAMELLIBRANCHIATA—*contd.*								
Palæarca quadrata (*Salter*) ..				×				Mulloch Hill, Rough Neuk.
,, modiolaris (*Salter*) ..			×					Mulloch Hill, Rough Neuk.
Pterinea Sowerbyi (*M'Coy*) ..				×				Starfish Bed.
,, tenuistriata (*M'Coy*) .	×							Camregan Wood.
Pleurorhynchus dipterus (*Salter*)							×	Craighead, Balclatchie conglomerate, Minuntion.
,, pristis (*Salt.*) ..			×					Mulloch Hill, Rough Neuk.
GASTEROPODA.								
Acroculia haliotis (*Sow.*)				×				Thraive Glen.
,, sp.			×					Mulloch Hill, High Road Quarries.
Bucania profunda (*Hall*)							×	Craighead.
,, sp.							×	Ardmillan, Balclatchie, Dow Hill.
,, sp.					×			Shalloch Mill.
Cyclonema carinatum					×			Shalloch Mill.
,, sp.	×							Cuddystone Glen, Penkill.
,, sp.					×			Shalloch Mill.
Cyrtolites euryomphalus (*Linds.*)? ..		×						Newlands.
,, orbiculus (*Linds.*)? ..							×	Balclatchie conglomerate.
,, sp.							×	Balclatchie, Craighead.
Enomphalus funatus (*Sow.*) ..					×			Shalloch Mill.
,, sp.					×			Whitehouse Bay.
,, granulatus (*Portl.*)			×					Mulloch Hill, Rough Neuk.
,, qualteriatus (*Schl.*)		×						Newlands.
,, sp.				×				Thraive Glen.
,, sp.			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
,, sp.	×							Cuddystone Glen, Penkill.
Fusispira elongata (*Hall*)? ..		×						Woodland Point.
,, sp.		×						Woodland Point.
Holopella obsoleta (*Sow.*) ..				×				Thraive Glen.
			×					Mulloch Hill, Rough Neuk.
,, sp.		×						Woodland Point.
,, tenuicincta (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
Holopea paludiniformis (*Hall*) ..							×	Craighead.
,, lymnæoides (*Forbes*) ..				×				Thraive Glen.
Loxonema elegans (*M'Coy*) ..				×				Thraive Glen.
Murchisonia obscura (*Portl.*) ..				×				Thraive Glen.
,, (Pleurotomaria) bicincta (*Hall*)					×			Shalloch Mill.
,, simplex (*M'Coy*) ..							×	Balclatchie.
,, cancellatula (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, sp.					×			Shalloch Mill.
,, sp.		×						Woodland Point.
Oriostoma discors (*Sow.*)		×						Woodland Point.
					×			Shalloch Mill.
,, angulatum (*Linds.*) ?			×					Mulloch Hill, Rough Neuk.
Ophileta nerine (*Billings*) ..					×			Shalloch Mill.
,, compacta (*Salter*) ..					×			Shalloch Mill.
				×				Threave Glen.
,, sp.							×	Craighead.
Pleurotomaria turrita (*Portlock*)				×				Thraive Glen.
,, alata (*Sow.*) ..		×						Woodland Point.
,, scutulata (*Linds.*)		×						Woodland Point.
,, trochiformis (*Portl.*) ..							×	Ardmillan.
,, claustrata (*Linds.*)			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.	×							Penkill, Bargany Pond Burr.
Platyceras cornutum (*Hisinger*)		×						Newlands.
	×							Camregan Wood.
,, sp.							×	Craighead.
Platyschisma helicites (*Sow.*) ..				×				Thraive Glen.
Raphistoma sp.							×	Ardmillan, Dow Hill, Balclatchie.
,, planistria, var. parva (*Hall*) ? ..				×				Thraive Glen.
,, æqualis (*Salter*)? ..							×	Balclatchie conglomerate.
Trochus Moorei (*M'Coy*)			×					Mulloch Hill, Rough Neuk.
Trochonema sp.			×					Mulloch Hill, Rough Neuk.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
GASTEROPODA—*continued.*								
Metoptoma sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
Helminthochiton (Chelodes) Grayæ (*H. (Woodward)* ..				×				Thraive Glen.
,, sp.							×	Balclatchie.
,, sp.							×	Ardmillan, Dow Hill.
PTEROPODA?								
Conularia elongata (*Portl.*) ..							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
,, Sowerbyi (*Defrance*) ..							×	Craighead.
,, bilineata (*Linds.*) ..			×					Mulloch Hill, Rough Neuk.
				×				Thraive Glen, Starfish Bed.
,, subtilis (*Salter*) ..		×						Woodland Point.
,, aspersa (*Linds.*)? ..		×						Woodland Point.
Hyolithes elegans (*Barr.*) ..				×				Thraive Glen.
,, (Theca) operculatus (*Salter*) ..							×	Balclatchie.
,, ,, triangularis (*Portl.*) ..					×			Whitehouse Bay.
				×				Thraive Glen.
							×	Ardmillan.
,, acutus (*Eichwald*) ..							×	Balclatchie.
,, reversus (*Salt.*) ..				×				Thraive Glen.
					×			Shalloch Mill, Whitehouse Bay.
,, sp.							×	Balclatchie, Dow Hill, Ardmillan.
,, sp.							×	Craighead.
,, sp.							×	Ardmillan.
,, sp.	×							Penkill.
,, sp.			×					Mulloch Hill, Rough Neuk.
Pterotheca corrugata (*Salter*) ..							×	Balclatchie.
,, transversa (*Salter*) ..							×	Ardmillan.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
,, sp	×							Penkill.
,, sp.					×			Shalloch Mill.
HETEROPODA.								
Ecculiomphalus Bucklandi (*Portl.*) ..					×			Shalloch Mill.
							×	Ardmillan, Dow Hill, Craighead.
,, lævis *Sow.*) ..					×			Shalloch Mill.
							×	Craighead, Balclatchie.
,, sp.		×						Woodland Point.
,, sp.							×	Craighead.
Bellerophon wenlockensis (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, carinatus (*Sow.*) ..					×			Shalloch Mill.
				×				Thraive Glen.
,, dilatatus (*Sow.*) ..			×					Mulloch Hill, Rough Neuk, Craigens Quarry, and in Wood.
		×						Woodland Point.
,, sphæra (*Linds.*)? ..		×						Woodland Point.
,, bilobatus (*Sow.*) ..				×				Thraive Glen, Starfish Bed.
							×	Ardmillan, Dow Hill, Balclatchie.
,, trilobatus (*Sow.*) ..				×				Thraive Glen.
							×	Ardmillan.
	×							Penkill.
		×						Woodland Point.
,, expansus (*Sow.*) ..			×					Mulloch Hill, High Road.
				×				Drummuck.
							×	Ardmillan, Balclatchie.
,, punctifrons (*Emmons*) ..							×	Craighead.
,, subdecussatus (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
				×				Drummuck.
,, Urei (*Fleming*) ..				×				Drummuck.
,, squamosus (*Linds.*)			×					Mulloch Hill.
,, elongatus (*Portlock*)				×				Thraive Glen.
,, Argo (*Billings*)? ..				×				Thraive Glen.
					×			Shalloch Mill.
,, sp.	×							Penkill.
sp.		×						Newlands, Woodland Point.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
HETEROPODA—*continued.*								
Bellerophon sp.					×			Shalloch Mill.
,, sp.							×	Balclatchie conglomerate.
,, sp.							×	Craighead, Ardmillan, Balclatchie, Dow Hill.
Maclurea magna (*Lesueur*) ..							×	Aldons, Tramitchell, Minuntion.
,, matutina (*Hall*) ? ..							×	Balclatchie conglomerate.
,, Logani (*Salter*)							×	Craighead.
,, macromphala (*M'Coy*)							×	Craighead.
CEPHALOPODA.								
Orthoceras politum (*M'Coy*) ..						×		Pinmore, Waterfall Penwhapple Glen.
,, Avelini (*Salter*) ..							×	Ardmillan.
,, bilineatum (*Hall*) ..							×	Craighead.
					×			Shalloch Mill.
,, arcuoliratum (*Hall*)					×			Shalloch Mill.
,, ludense (*Sow.*) ..					×			Shalloch Mill.
				×				Thraive Glen.
,, vagans (*Salter.*) ..					×			Shalloch Mill.
				×				Thraive Glen.
,, tenuicinctum (*Portl.*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
,, distans (*Sow.*) ..		×						Woodland Point.
				×				Starfish Bed.
,, imbricatum (*Wahl.*)			×					Mulloch Hill, Rough Neuk, High Road Quarry.
		×						Woodland Point.
	×							Penkill, Cuddystone Glen.
,, tracheale (*Sow.*) ..		×						Woodland Point.
,, mocktreense (*Sow.*)..		×						Woodland Point.
,, bullatum (*Sow.*) ..					×			Whitehouse Bay.
		×						Woodland Point.
,, primævum (*Forbes*)..	×							Penkill.
				×				Thraive Glen.
,, angulatum (*Wahl.*) ..			×					Mulloch Hill, Ptilograptus Bed.
		×						Woodland Point, Newlands.
	×							Penkill.
,, Bacchus (*Barr.*) ..	×							Penkill, Bargany Pond Burn.
	×							Penwhapple Glen, Penkill Beds.
,, annulatum (*Sow.*) ..	×							Penwhapple Glen.
,, Grindrodi (*Blake*) ..	×							Penkill Beds, Penwhapple Glen.
,, fusiforme (*Hall*) ? ..	×							Penkill, Penwhapple Glen.
,, multicinctum (*Hall*)	×							Penkill.
,, sp.	×							Camregan Wood.
,, gracile (*Portlock*) ..					×			Shalloch Mill.
,, subundulatum (*Portl.*)							×	Dow Hill.
,, sp.				×				Thraive Glen.
Phragmoceras arcuatum (*Sow.*)..			×					Mulloch Hill, Rough Neuk.
,, sp.		×						Woodland Point.
,, sp.							×	Balclatchie conglomerate.
Endoceras proteiforme, var. strangulatum (*Hall*)				×			×	Thraive Glen. Balclatchie, Dow Hill.
Gomphoceras sp.	×							Penkill.
,, crater (*Blake*) ..		×						Woodland Point.
,, cinctum (*Blake*) ..	×							Camregan Wood.
Potterioceras sp.	×							Penkill.
Cyrtoceras victor (*Barr.*)? ..				×				Starfish Bed.
,, arcuatum (*Hall*)		×						Woodland Point.
,, sp.								Craighead.
,, sp.							×	Balclatchie conglomerate.
,, compressum (*Sow.*) ..	×							Penkill.
,, scoticum (*Blake*) ..							×	Craighead, Minuntion.
,, annulatum (*Hall*) ..			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Minuntion.
Oncoceras sp.			×					Mulloch Hill.
,, sp.		×						Woodland Point.
,, sp.		×						Newlands.
Trocholites planorbiformis (*Conrad*) ..							×	Craighead
,, cornuarietis (*Sow.*)..			×					Mulloch Hill, Rough Neuk.
Trochoceras aspersum (*Barr.*)?..		×						Woodland Point.

No. 4.—Complete List of Fossils from the Stinchar Limestone Series (Upper Llandeilo) of the Girvan District of the South of Scotland.

Algæ. (?)

Girvanella problematica (*Nich. & Eth.*)

Rhizopoda?

Nidulites favus (*Salter*).

Foraminifera.

Saccammina Carteri (*Brady*).

Hydrozoa.

Cryptograptus tricornis (*Carr.*)
Clathrograptus cuneiformis (*Lapw.*)
Climacograptus bicornis (*Hall*).
,, nanus.
,, Schärenbergi (*Lapw.*)
Dicellograptus sextans (*Hall*).
,, sp.
Dicranograptus ramosus (*Hall*).
,, sp.
Didymograptus superstes (*Lapw.*)
,, sp.
Diplograptus foliaceus (*Murch.*)
,, rugosus (*Emm.*)
,, sp.
Glossograptus Hincksi (*Hopk.*)

Cœlenterata.

Actinozoa.

Chætetes (*Fischer*).
Favosites girvanensis (*Nich. and Eth.*)
Fistulipora pilula (*Nich. and Eth.*)
Halysites sp.
Heliolites Grayi (*Edw. and Haime*).
Labechia canadensis (*N. and Murie*).
Lindströmia subduplicata (*M'Coy*).
Lyopora favosa (*M'Coy*).
Monticulipora girvanensis (*Nich.*)
Petraia elongata (*Phil.*)
Prasopora Grayæ (*Nich. and Eth.*)
Propora Edwardsi (*Nich. and Eth.*)
Stenopora fibrosa (*Goldf.*)
Streptelasma æquisulcatum (*M'Coy*).
,, aggregatum (*N. and E.*)
,, craigense (*M'Coy*).
,, europæum (*Röm.*)
Stylaræa occidentalis (*Nich. and Eth.*)
Tetradium Peachi (*Nich. and Eth.*)
Thecostegites scoticum (*Nich. and Eth.*)

Crinoidea.

Glyptocrinus (*Hall*) sp.

Annelida.

Cornulites (*Schl.*) sp.
Serpulites longissimus (*Murch.*)

Cirripedia.

Turrilepas (*Woodw.*) sp.

Ostracoda.

Cythere aldensis (*M'Coy*).
,, ,, var. major (*Jones*).
,, grayana (*Jones*).
,, wrightiana (*Jones and Holl.*)
Primitia barrandiana (*Jones*).

Trilobita.

Ampyx (*Dalm.*) sp.
Asaphus (Isotelus) gigas (*Dekay*).
,, ,, rectifrons (*Portl.*)
Bronteus (*Goldf.*) sp.
Calymene Blumenbachi (*Brong.*)
Cheirurus bimucronatus (*Murch.*)
,, gelasinosus (*Portl.*)
Dindymene (*Corda.*) sp.
Encrinurus punctatus (*Brün.*)
,, ,, var. arenaceus (*Salt.*)
,, ,, var. calcareus (*Salt.*)
Harpes (*Goldf.*) sp.
Illænus (Dysplanus) æmulus (*Salt.*)
,, ,, Bowmani (*Salt.*)
,, ,, latus (*M'Coy*).
,, Portlocki (*Salt.*)
,, sp.
Lichas hibernicus (*Portl.*)
Phacops Brongniarti (*Portl.*)
Remopleurides Barrandei (*Eth. & Nich.*)
,, Colbii (*Portl.*)
,, laterispinifer (*Portl.*)
,, sp.
Sphærexochus mirus (*Beyr.*)
Trinucleus (*Lhwyd*). sp.

Brachiopoda.

Acrotreta Nicholsoni (*Dav.*)
Crania siluriana (*Dav.*)
,, sp.
Discina perrugata (*M'Coy*).
Leptæna Etheridgei (*Dav.*)
,, Grayi (*Dav.*)
,, llandeiloensis (*Dav.*)
,, (Plectambonites) quinquecostata (*M'Coy*).

BRACHIOPODA—*continued.*

,, sericea (*Sow.*)
,, ,, var. rhombica (*M'Coy*).
,, (Christiania) tenuicincta (*M'Coy*).
,, (Plectambonites) transversalis (*Wahl.*)
,, youngiana (*Dav.*)
Lingula attenuata (*Sow.*)
,, granulata (*Phil.*)
,, ovata (*M'Coy*).
,, quadrata (*Eichw.*)
,, Ramsayi (*Salt.*)
Meristella angustifrons ? (*M'Coy*).
Nucleospira pisum (*Sow.*)
Orthis balcletchiensis (*Dav.*)
,, (Platystrophia) biforata (*Schl.*)
,, calligramma (*Dalm.*)
,, ,, var. virgata (*Salt.*)
,, ,, var. scotica (*Dav.*)
,, confinis (*Salt.*)
,, crispa (*M'Coy*).
,, (Dalmanella) elegantula (*Dalm.*)
,, (Dinorthis) flabellulum (*Sow.*)
,, girvanensis (*Dav*)
,, intercostata (*Portl.*)
,, protensa (*Sow.*)
,, sowerbyana (*Dav.*)
,, (Dalmanella) testudinaria (*Dalm.*)
,, turgida (*M'Coy*).
,, unguis (*Sow.*)
,, vespertilio (*Sow.*)
Rhynchonella æmula (*Salt.*)
,, balcletchiensis (*Dav.*)
,, Lapworthi (*Dav.*)
,, nasuta (*M'Coy*).
,, Peachi (*Dav.*)
,, (Hyattella) portlockiana (*Dav.*)
,, Salteri (*Dav.*)
,, scotica (*Dav.*)
,, sub-borealis (*Dav.*)
,, Thomsoni (*Dav.*)
,, Weaveri (*Salt.*)
Siphonotreta anglica (*Morris*).
,, micula (*M'Coy*).
,, scotica (*Dav.*)
Strophomena corrugatella (*Dav.*)
,, (Rafinesquina) deltoidea (*Conr.*)
,, (Rafinesquina) expansa (*Sow.*)
,, Grayi (*Dav.*)
,, imbrex (*Pand.*), var. semiglobosa (*Dav.*)
,, llandeiloensis (*Dav.*)
,, retroflexa (*Salt.*)
,, (Leptæna) rhomboidalis (*Wilck.*)
,, sp.

BRACHIOPODA—*continued.*

Triplesia Grayæ (*Dav.*)
,, sp.

LAMELLIBRANCHIATA.

Ambonychia amygdalina (*Hall*).
,, radiata (*Emm.*)
Orthonota contracta (*Hall*).
Pleurorhynchus dipterus (*Salt.*)

GASTEROPODA.

Bellerophon acutus (*Sow.*)
,, punctifrons (*Emm.*)
,, sp.
,, (Bucania) profunda (*Hall*).
Chelodes (*Dav. and King*).
,, (Helminthochiton) sp.
Cyrtolites (*Conrad*) sp.
Ecculiomphalus Bucklandi (*Portl.*)
,, lævis (*Sow.*)
,, sp.
Holopea paludiniformis (*Hall*).
Maclurea Logani (*Salt.*)
,, (Ophileta) macromphala (*M'Coy*).
,, Maccoyi (*Salt.*)
,, magna (*Lesu.*)
,, matutina (*Hall*).
Macrocheilus (*Phillips*) sp.
Metoptoma (*Phil.*) sp.
,, (Tryblidium) sp.
Murchisonia angulata (*Sow.*)
,, (Pleurotomaria) bicincta (*Hall*).
,, gracilis (*Hall*).
,, gyrogonia (*M'Coy*).
,, vitellia (*Bill.*)
Ophileta (*Vanux*) sp.
Pleurotomaria (*Defr.*)
,, (Raphistoma) lenticularis (*Sow.*)
,, qualteriata (*Schl.*)
Platyceras (*Conr.*) sp.

PTEROPODA. (?)

Conularia elongata (*Portl.*)
,, Sowerbyi (*Defr.*)
Hyolithes (*Eichw.*) sp.
Theca (*Sow.*) sp.

CEPHALOPODA.

Cyrtoceras inæquiseptum (*Portl.*)
,, multicamaratum (*Hall*).
,, scoticum (*Blake*).
,, sp.
Orthoceras bilineatum (*Hall*).
,, pendens (*Blake*).
,, politum (*M'Coy*).
,, sp.
Trocholites planorbiformis (*Conrad.*)

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
OSTRACODA—*continued.*								
Primitia Krausei (*Jones*) ..					×			Whitehouse Bay.
,, girvanensis (*Jones*) ..					×			Whitehouse Bay.
,, Grayæ (*Jones*)					×			Whitehouse Bay.
,, mundula, var. fimbriata (*Jones*) ..					×			Whitehouse Bay.
,, mundula, var. klœdeniana (*Jones*)..					×			Whitehouse Bay.
,, ulrichiana (*Jones*) ..					×			Whitehouse Bay.
,, barrandiana (*Jones*) ..							×	Aldons.
Beyrichia Klœdeni (*M'Coy*) ..				×				Thraive Glen, Whitehouse Bay.
,, ,, var. infecta (*Jones*) ..					×			Whitehouse Bay.
,, ,, var. Scotica (*Jones & Holl.*)	×							Bargany Pond Burn.
,, impar (*Jones*)					×			Whitehouse Bay.
,, comma (*Jones*).. ..				×				Thraive Glen.
Ulrichia girvanensis (*Jones*) .					×			Whitehouse Bay.
,, sp.					×			Whitehouse Bay.
,, Grayæ (*Jones*)	×							Bargany Pond Burn.
Sulcuna præurrens (*Jones*) ..					×			Whitehouse Bay.
Cypridina Grayæ (*Jones*) ..					×			Whitehouse Bay.
Cythere aldensis (*M'Coy*) ..							×	Aldons.
,, ,, var. major (*Jones*) ..							×	Aldons.
,, grayana (*Jones*) ..							×	Aldons.
,, wrightiana (*Jones and Holl.*)							×	Aldons.
,, sp.		×						Newlands.
,, sp.							×	Auchensoul.
PHYLLOPODA AND CIRREPEDIA.								
Pinnocaris Lapworthi (*Eth., jun.*) ..							×	Balclatchie, Ardmillan.
,, sp.				×				Drummock, Starfish Bed.
Turrilepas Peachi (*E. and N.*) ..					×			Whitehouse Bay.
,, sp.				×				Thraive Glen.
,, scotica (*E. and N.*) ..							×	Balclatchie, Dow Hill, Ardmillan.
,, sp.		×						Newlands.
POLYZOA.								
Fenestella assimilis (*Lonsd.*) ..		×						Woodland Point.
,, patula (*M'Coy*) ..	×							Penkill.
		×						Woodland Point.
,, Milleri (*Lonsd.*) ..		×						Woodland Point.
,, subantiqua (*D'Orbigny*) ..	×							Penkill.
		×						Woodland Point.
,, sp.			×					Mulloch Hill, Rough Neuk.
,, sp.			×					Mulloch Hill, High Road.
,, sp.		×						Newlands.
,, sp.					×			Shalloch Mill.
Glauconome disticha (*Goldf.*) ..		×						Woodland Point.
Gorgonia regularis (*Portl.*) ..		×						Woodland Point.
Hippothoa inflata (*Nich.*) ..		×						Woodland Point.
Rhinopora verrucosa (*Hall*) ..		×						Woodland Point.
Retepora sp.							×	Balclatchie.
			×					Mulloch Hill, Rough Neuk.
Ptilodictya costellata (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, dichotoma (*Portl.*) ..							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
		×						Woodland Point.
	×							Penkill, Bargany Pond Burn.
,, sp.							×	Dow Hill.
,, lanceolata (*Goldf.*) ..		×						Woodland Point.
BRACHIOPODA.								
Lingula canadensis (*Billings*) ..							×	Balclatchie conglomerate.
,, quadrata (*Eichwald*) ..					×			Shalloch Mill.
							×	Craighead.
,, Ramsayi (*Salter*) ..							×	Craighead, Balclatchie, Minuntion.
,, granulata (*Phillips*) ..							×	Ardmillan, Balclatchie, Minuntion.
				×				Drummuck.
,, attenuata (*Sow.*) ..					×			Shalloch Mill, Whitehouse Bay.
							×	Balclatchie, Ardmillan, Dow Hill.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Lingula ovata (*M'Coy*)				×			×	Craighead.
								Drummuck.
			×					Mulloch Hill, Rough Neuk.
,, brevis (*Portlock*) ..					×		×	Ardmillan.
								Shalloch Mill, Whitehouse Bay.
,, Symondsi (*Salter*) ..	×							Penkill, Bargany Pond Burn.
		×						Woodland Point.
Dinobolus Davidsoni (*Salter*) ..			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
Orbiculoidea Forbesi (*Dav.*) ..			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
Discina oblongata (*Portl.*) ..							×	Balclatchie, Ardmillan, Dow Hill.
,, perrugata (*M'Coy*) ..					×		×	Balclatchie, Ardmillan, Craighead.
								Shalloch Mill.
.. crassa (*Hall*)?	×							Penwhapple Glen.
,, rugata (*Sow.*)	×							Bargany Pond Burn.
Paterula balcletchiensis (*Dav.*)				×			×	Balclatchie.
								Starfish Bed, Thraive.
Siphonotreta scotica (*Dav.*) ..				×			×	Craighead, Minuntion, Starfish Bed.
,, micula *M'Coy*) ..							×	Balclatchie, Ardmillan.
Acrothele granulata (*Linnr.*) .							×	Dow Hill.
		×						Woodland Point.
Crania siluriana (*Dav.*)			×					Mulloch Hill, Rough Neuk, High Road Quarries.
,, llandoveriana (*Dav.*) ..		×						Newlands.
,, sp.				×				Starfish Bed, Thraive.
,, sp.							×	Ardmillan, Craighead.
			×					Mulloch Hill, Rough Neuk, High Road Quarries.
,, sp.	×							Penkill.
		×						Woodland Point, Newlands.
Pholidops implicata (*Sow.*) ..					×			Shalloch Mill.
	×							Bargany Pond Burn.
Acrotreta Nicholsoni (*Dav.*) ..							×	Craighead, Balclatchie, Ardmillan.
,, costata (*Dav.*)							×	Balclatchie.
Spirifera plicatella, var. radiata (*Sow.*)	×							Bargany Pond Burn, Penkill.
Cyrtia exporrecta (*Wahl.*) ..	×							Penkill.
Nucleospira pisum (*Sow.*) ..	×							Bargany Pond Burn.
Meristella (Whitfieldia) tumida (*Dalm.*) ..	×							Bargany Pond Burn.
,, angustifrons (*M'Coy*)			×					Mulloch Hill, Rough Neuk, High Road.
				×				Auldthorns.
Athyris sp.					×			Whitehouse Bay.
Glassia obovata (*Sow.*)	×							Penkill.
Merista cymbula (*Dav.*)				×				Thraive, Drummuck.
Atrypa reticularis (*Linn.*) ..	×							Penkill, Penkill Limestone, Penwhapple Glen.
		×						Woodland Point.
			×					Mulloch Hill, Rough Neuk, High Road.
,, imbricata (*Sow.*)	×							Penkill, Bargany Pond Burn.
		×						Woodland Point.
,, scotica (*M'Coy*)?			×					Mulloch Hill.
Triplesia Grayæ (*Dav.*)							×	Craighead.
,, spiriferoides (*M'Coy*) ..				×				Starfish Bed, Thraive Glen.
							×	Ardmillan.
,, monilifera (*M'Coy*) ..		×						Woodland Point.
,, incerta (*Dav.*)	×							Penkill, Bargany Pond Burn, Cuddystone Glen.
,, sp.							×	Craighead.
Porambonites interoedens (*Pander*) ..					×			Shalloch Mill.
Leptocœlia hemispherica (*Sow.*)	×							Camregan Wood.
				×				Auldthorns.
			×					Mulloch Hill, Rough Neuk, High Road.
Pentamerus oblongus (*Sow.*) ..	×							Penkill, Cuddystone Glen.
		×						Newlands.
,, globosus (*Sow.*) ..	×							Penkill.
,, undatus (*Sow.*) ..		×	×					Woodland Point, Newlands, Ptilograptus Bed, Craigens Quarry.
	×							Penkill, Cuddystone Glen.
,, galeatus (*Sow.*) ..	×							Penkill.
,, rotundus (*Sow.*) ..	×							Penkill, Penkill Beds, Penwhapple Glen.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Pentamerus shallockiensis (*Dav.*)? ..					×			Shalloch Mill.
Stricklandinia lens (*Sow.*) ..		×	×					Woodland Point, Newlands, Mulloch Hill, Rough Neuk.
,, lirata (*Sow.*) ..		×						Woodland Point.
,, balcletchiensis (*Dav.*)							×	Balclatchie conglomerate.
Rhynchonella æmula (*Salter*) ..							×	Craighead.
,, Salteri (*Dav.*) ..							×	Craighead.
,, nasuta (*M'Coy*) ..							×	Craighead, Balclatchie, Minuntion.
,, Thomsoni (*Dav.*) ..							×	Craighead.
,, portlockiana (*Dav.*)							×	Craighead, Balclatchie.
,, Lapworthi (*Dav.*) ..							×	Craighead.
,, sub-borealis (*Dav.*)							×	Craighead.
,, cuneata (*Dalm.*) ..			×	×				Mulloch Hill, Rough Neuk, High Road.
		×						Auldthorns.
								Camregan Wood.
,, cuneata, var. ardmillanensis (*Dav.*)							×	Ardmillan.
,, cuneatella (*Dav.*) ..							×	Balclatchie conglomerate.
,, Peachi (*Dav.*) ..							×	Craighead.
,, Weaveri (*Salter*) ..							×	Craighead.
,, llandoveriana (*Dav.*)	×							Camregan Wood.
,, nucula (*Sow.*)? ..							×	Balclatchie conglomerate.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
,, scotica (*Dav.*) ..							×	Craighead.
,, girvanensis (*Dav.*)							×	Balclatchie conglomerate.
,, Wilsoni (*Sow.*) ..	×							Camregan Wood.
,, balclatchiensis (*Dav.*) ..							×	Balclatchie, Craighead, Minuntion.
,, decemplicata (*Sow.*)			×					Mulloch Hill.
,, sp.							×	Craighead, Balclatchie conglomerate.
,, sp.		×						Newlands.
,, sp.							×	Dow Hill, Ardmillan.
,, sp.				×				Starfish Bed, Thraive Glen.
Skenidium Lewisii, var. woodlandensis (*Dav.*)		×						Woodland Point.
,, Grayi (*Dav.*)				×				Starfish Bed, Thraive Glen.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
					×			Shalloch Mill.
Orthis biloba (*Linn.*)		×						Woodland Point.
	×							Bargany Pond Burn.
,, polygramma, var. centlandica (*Dav.*)	×							Penkill.
		×						Woodland Point.
,, turgida (*M'Coy*) ..	×							Penkill Limestone, Penwhapple Glen.
,, Bouchardi, var. balclatchiensis (*Dav.*) ..							×	Craighead, Balclatchie conglomerate.
,, biforata (*Schloth.*)							×	Craighead, Balclatchie conglomerate.
	×						×	Craighead.
								Penkill Limestone, Penwhapple Glen.
,, calligramma (*Dalm.*) ..					×			Shalloch Mill.
							×	Craighead, Aldons, Tramitchell.
							×	Ardmillan, Minuntion.
		×						Shalloch Forge.
,, ,, var. scotica (*Dav.*) ..							×	Craighead.
,, ,, var. virgata (*Salter*) ..							×	Balclatchie Beds, Doularg.
,, ,, var. plicata (*Sow.*) ..							×	Balclatchie Beds, Ardmillan.
		×						Woodland Plint.
,, mullockensis (*Dav.*) ..			×					Mulloch Hill, Rough Neuk, High Road.
				×				Auldthorns, Starfish Bed, Thraive Glen.
,, confinis (*Salter*)							×	Minuntion, Benan Burn, Doularg, Tramitchell.
,, vespertillio (*Sow.*)..							×	Craighead.
					×			Shalloch Mill.
,, girvanensis (*Dav.*)							×	Craighead.
,, intercostata (*Portl.*)							×	Aldons.
,, Lapworthi (*Dav.*) .. .					×			Shalloch Mill.
							×	Balclatchie conglomerate.
,, testudinaria (*Dal.*) .					×			Shalloch Mill.
							×	Craighead, Balclatchie, Dow Hill, Ardmillan.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Orthis flabellulum (*Sow.*) ..				×				Starfish Bed, Thraive Glen.
							×	Craighead, Ardmillan.
,, crispa (*M'Coy*)				×				Starfish Bed.
							×	Ardmillan.
,, kilbuchoensis (*Dav.*) ..							×	Ardmillan.
,, sagittifera (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
				×				Starfish Bed.
,, sowerbyana (*Dav.*) ..					×			Shalloch Mill.
							×	Craighead, Balclatchie conglomerate.
	×							Penkill, Bargany Pond Burn.
		×						Newlands, Woodland Point.
			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
,, elegantula (*Dal.*)				×				Thraive Glen.
					×			Shalloch Mill.
							×	Craighead, Balclatchie.
,, nina (*Dav.*)					×			Whitehouse Bay.
			×					Mulloch Hill, Rough Neuk, and in Wood.
,, rustica (*Sow.*)	×							Cuddystone Glen, Penkill Beds, Penwhapple Glen.
		×						Woodland Point.
,, ,, var. rigida (*Dav.*)	×							Penkill Beds, Penwhapple Glen.
,, Actoniæ (*Sow.*)				×				Starfish Bed.
,, reversa (*Salter*)	×							Penkill Beds, Penwhapple Glen.
,, protensa (*Sow.*)							×	Benan Crag.
,, Rankini (*Dav.*)				×				Starfish Bed.
							×	Ardmillan.
,, Carausii (*Salter*)							×	Ardmillan.
,, sp.					×			Shalloch Mill.
,, sp.							×	Balclatchie Beds.
,, sp.							×	Ardmillan.
,, sp.				×				Starfish Bed.
Strophomena Walmstedti (*Linds.*)	×							Cuddystone Glen.
	×							Penkill, Penwhapple Glen.
		×						Newlands, Woodland Point.
			×					Mulloch Hill, Rough Neuk, Craigens, Ptilograptus Bed.
Strophomena rhomboidalis (*Wilck.*) ..				×				Starfish Bed, Thraive Glen, Auldthorns.
					×			Shalloch Mill.
							×	Craighead.
,, applanata (*Salter*)	×							Penkill, Bargany Pond Burn, Cuddystone Glen.
		×						Newlands.
,, pecten (*Linn.*) ..		×						Newlands, Woodland Point.
	×							Bargany Pond Burn, Penkill.
,, antiquata (*Sow.*) ..		×						Woodland Point.
			×					Mulloch Hill, Rough Neuk.
,, imbrex, var. semiglobosina (*Dav.*)							×	Craighead, Balclatchie conglomerate.
	×							Camregan Wood.
,, compressa (*Sow.*) ..							×	Ardmillan.
,, simulans (*M'Coy*) ..					×			Shalloch Mill.
,, insculpta (*Hall*) ..							×	Ardmillan.
,, llandeiloensis (*Dav.*)							×	Craighead, Ardmillan.
,, deltoidea (*Conrad.*)							×	Balclatchie conglomerate, Craighead, Dow Hill, Ardmillan.
		×						Woodland Point.
,, retroflexa (*Salter*)							×	Craighead, Dow Hill, Ardmillan, Balclatchie conglomerate.
							×	Balclatchie, Benan Crag, Dow Hill, Ardmillan.
,, corrugatella (*Dav.*)		×	×					Woodland Point, Newlands, Rough Neuk.
					×			Shalloch Mill.
							×	Craighead, Minuntion, Doularg, Ardmillan.
,, expansa (*Sow.*) ..				×				Auldthorns.
			×					Mulloch Hill, Rough Neuk, High Road.
,, grandis (*Sow.*) ..				×				Thraive Glen.
,, arenacea (*Salter*) ..	×							Camregan Wood.
		×						Woodland Point.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
BRACHIOPODA—*continued.*								
Strophomena Waltoni (*Dav.*)	×				•			Cuddystone Glen.
,, shallockiensis (*Dav.*)					×			Shalloch Mill.
,, sp.							×	Dow Hill, Ardmillan, Craighead.
,, sp.					×			Shalloch Mill.
Leptæna sericea (*Sow.*)	×							Penkill, Camregan Wood.
			×					Mulloch Hill, Rough Neuk.
					×			Shalloch Mill.
				×				Starfish Bed, Auldthorns.
							×	Craighead, Minuntion, Balclatchie.
,, ,, var. rhombica (*M'Coy*)							×	Craighead, Balclatchie conglomerate.
,, transversalis (*Wahl.*)	×							Camregan Wood, Penkill, Bargany Pond Burn.
		×						Woodland Point, Newlands, Ptilograptus Bed.
				×				Auldthorns, Starfish Bed.
							×	Craighead, Balclatchie conglomerate.
,, quinquecostata (*M'Coy*)		×						Woodland Point.
					×			Shalloch Mill.
							×	Ardmillan, Balclatchie.
,, tenuicincta (*M'Coy*)					×			Shalloch Mill.
							×	Balclatchie, Ardmillan.
							×	Balclatchie conglomerate.
,, segmentum (*Angelin*)		×						Woodland Point.
	×							Cuddystone Glen.
					×			Shalloch Mill.
,, youngiana (*Dav.*)							×	Craighead, Balclatchie conglomerate.
,, Etheridgei (*Dav.*)							×	Craighead.
,, llandeiloensis (*Dav.*)							×	Craighead Ardmillan.
,, Grayii (*Dav.*)							×	Craighead.
,, scissa (*Salt.*)		×						Woodland Point.
							×	Balclatchie, Ardmillan.
LAMELLIBRANCHIATA.								
Ambonychia radiata (*Emmons*)							×	Ardmillan.
					×			Shalloch Mill.
							×	Craighead.
,, orbicularis (*Conrad.*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
,, amygdalina (*Hall*)		×						Woodland Point.
							×	Craighead.
,, bellistriata (*Hall*)	×							Penkill.
,, sp.							×	Ardmillan, Dow Hill.
,, sp.	×							Penkill.
Avicula elliptica (*Hall*)		×						Woodland Point.
,, sp.							×	Ardmillan.
,, sp.	×							Penkill.
Cardiola striata (*Sow.*)	×							Penkill.
,, sp.		×						Woodland Point.
,, fibrosa (*Sow.*)	×							Penwhapple Glen.
Ctenodonta astartæformis (*Salter*)							×	Ardmillan, Dow Hill.
,, varicosa (*Salter*)							×	Ardmillan.
,, Eastnori (*Murch.*)				×				Thraive Glen.
,, levata (*Hall*)							×	Balclatchie.
,, sp.			×					Mulloch Hill, Rough Neuk.
Nucula subacuta (*M'Coy*)							×	Balclatchie.
Goniophora cymbæformis (*Sow.*)	×							Penkill.
		×						Woodland Point.
,, sp.							×	Ardmillan.
Mytilus semirugatus (*Portl.*)	×							Penkill, Bargany Pond Burn.
,, gradatus (*Salter*)					×			Shalloch Mill.
,, mytilimeris (*Conrad.*)		×						Woodland Point.
	×							Penkill.
Lunulicardium elegans (*Salter*)	×							Penwhapple Glen.
Orthonota undata (*Sow.*)			×					Mulloch Hill, Rough Neuk, and in Wood.
		×						Newlands.
,, contracta (*Hall*)							×	Craighead.
,, prora (*Salter*)				×				Starfish Bed.
semisulcata (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, rigida (*Sow.*)	×							Camregan Wood.
,,	×							Penkill, Cuddystone Glen.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
LAMELLIBRANCHIATA—*contd.*								
Palæarca quadrata (*Salter*) ..				×				Mulloch Hill, Rough Neuk.
,, modiolaris (*Salter*) ..			×					Mulloch Hill, Rough Neuk.
Pterinea Sowerbyi (*M'Coy*) ..				×				Starfish Bed.
,, tenuistriata (*M'Coy*) ..	×							Camregan Wood.
Pleurorhynchus dipterus (*Salter*)							×	Craighead, Balclatchie conglomerate, Minuntion.
,, pristis (*Salt.*) ..			×					Mulloch Hill, Rough Neuk.
GASTEROPODA.								
Acroculia haliotis (*Sow.*).. ..				×				Thraive Glen.
,, sp.			×					Mulloch Hill, High Road Quarries.
Bucania profunda (*Hall*).. ..							×	Craighead.
,, sp.							×	Ardmillan, Balclatchie, Dow Hill.
,, sp.					×			Shalloch Mill.
Cyclonema carinatum					×			Shalloch Mill.
,, sp.	×							Cuddystone Glen, Penkill.
,, sp.					×			Shalloch Mill.
Cyrtolites euryomphalus (*Linds.*)? ..		×						Newlands.
,, orbiculus (*Linds.*)? ..							×	Balclatchie conglomerate.
,, sp.							×	Balclatchie, Craighead.
Enomphalus funatus (*Sow.*) ..					×			Shalloch Mill.
,, sp.					×			Whitehouse Bay.
,, granulatus (*Portl.*)			×					Mulloch Hill, Rough Neuk.
,, qualteriatus (*Schl.*)		×						Newlands.
,, sp.				×				Thraive Glen.
,, sp.			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
,, sp.	×							Cuddystone Glen, Penkill.
Fusispira elongata (*Hall*)? ..		×						Woodland Point.
,, sp.		×						Woodland Point.
Holopella obsoleta (*Sow.*) ..				×				Thraive Glen.
			×					Mulloch Hill, Rough Neuk.
,, sp.		×						Woodland Point.
,, tenuicincta (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk, Ptilograptus Bed.
Holopea paludiniformis (*Hall*) ..							×	Craighead.
,, lymnæoides (*Forbes*) ..				×				Thraive Glen.
Loxonema elegans (*M'Coy*) ..				×				Thraive Glen.
Murchisonia obscura (*Portl.*) ..				×				Thraive Glen.
,, (Pleurotomaria) bicincta (*Hall*)					×			Shalloch Mill.
,, simplex (*M'Coy*) ..							×	Balclatchie.
,, cancellatula (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
,, sp.					×			Shalloch Mill.
,, sp.		×						Woodland Point.
Oriostoma discors (*Sow.*).. ..		×						Woodland Point.
					×			Shalloch Mill.
,, angulatum (*Linds.*) ?			×					Mulloch Hill, Rough Neuk.
Ophileta nerine (*Billings*) ..					×			Shalloch Mill.
					×			Shalloch Mill.
,, compacta (*Salter*) ..				×				Threave Glen.
,, sp.							×	Craighead.
Pleurotomaria turrita (*Portlock*)				×				Thraive Glen.
,, alata (*Sow.*) ..		×						Woodland Point.
,, scutulata (*Linds.*)		×						Woodland Point.
,, trochiformis (*Portl.*) ..							×	Ardmillan.
,, claustrata (*Linds.*)			×					Mulloch Hill, Rough Neuk.
,, sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.	×							Penkill, Bargany Pond Burn.
Platyceras cornutum (*Hisinger*)		×						Newlands.
	×							Camregan Wood.
,, sp.							×	Craighead.
Platyschisma helicites (*Sow.*) ..				×				Thraive Glen.
Raphistoma sp.							×	Ardmillan, Dow Hill, Balclatchie.
,, planistria, var. parva (*Hall*) ? ..				×				Thraive Glen.
,, æqualis (*Salter*) ? ..							×	Balclatchie conglomerate.
Trochus Moorei (*M'Coy*).. ..			×					Mulloch Hill, Rough Neuk.
Trochonema sp.			×					Mulloch Hill, Rough Neuk.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
GASTEROPODA—*continued.*								
Metoptoma sp.							×	Craighead.
,, sp.					×			Shalloch Mill.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
Helminthochiton (Chelodes) Grayæ (*H. Woodward*) ..				×				Thraive Glen.
,, sp.							×	Balclatchie.
,, sp.							×	Ardmillan, Dow Hill.
PTEROPODA?								
Conularia elongata (*Portl.*) ..							×	Balclatchie, Dow Hill, Ardmillan, Craighead.
,, Sowerbyi (*Defrance*) ..							×	Craighead.
,, bilineata (*Linds.*) ..			×					Mulloch Hill, Rough Neuk.
				×				Thraive Glen, Starfish Bed.
,, subtilis (*Salter*) ..		×						Woodland Point.
,, aspersa (*Linds.*)? ..		×						Woodland Point.
Hyolithes elegans (*Barr.*) ..				×				Thraive Glen.
,, (Theca) operculatus (*Salter*) ..							×	Balclatchie.
,, ,, triangularis (*Portl.*) ..					×			Whitehouse Bay.
				×				Thraive Glen.
							×	Ardmillan.
,, acutus (*Eichwald*) ..							×	Balclatchie.
,, reversus (*Salt.*) ..				×				Thraive Glen.
					×			Shalloch Mill, Whitehouse Bay.
							×	Balclatchie, Dow Hill, Ardmillan.
,, sp.							×	Craighead.
,, sp.							×	Ardmillan.
,, sp.	×							Penkill.
,, sp.			×					Mulloch Hill, Rough Neuk.
Pterotheca corrugata (*Salter*) ..							×	Balclatchie.
,, transversa (*Salter*) ..							×	Ardmillan.
,, sp.				×				Thraive Glen.
,, sp.		×						Newlands.
,, sp	×							Penkill.
,, sp.					×			Shalloch Mill.
HETEROPODA.								
Ecculiomphalus Bucklandi (*Portl.*) ..					×			Shalloch Mill.
							×	Ardmillan, Dow Hill, Craighead.
,, lævis *Sow.*) ..					×			Shalloch Mill.
							×	Craighead, Balclatchie.
,, sp.		×						Woodland Point.
,, sp.							×	Craighead.
Bellerophon wenlockensis (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, carinatus (*Sow.*) ..					×			Shalloch Mill.
				×				Thraive Glen.
,, dilatatus (*Sow.*) ..			×					Mulloch Hill, Rough Neuk, Craigens Quarry, and in Wood.
		×						Woodland Point.
,, sphæra (*Linds.*)? ..		×						Woodland Point.
,, bilobatus (*Sow.*) ..				×				Thraive Glen, Starfish Bed.
							×	Ardmillan, Dow Hill, Balclatchie.
,, trilobatus (*Sow.*) ..				×				Thraive Glen.
							×	Ardmillan.
	×							Penkill.
		×						Woodland Point.
,, expansus (*Sow.*) ..			×					Mulloch Hill, High Road.
				×				Drummuck.
							×	Ardmillan, Balclatchie.
,, punctifrons (*Emmons*) ..							×	Craighead.
,, subdecussatus (*M'Coy*) ..			×					Mulloch Hill, Rough Neuk.
				×				Drummuck.
,, Urei (*Fleming*) ..				×				Drummuck.
,, squamosus (*Linds.*)			×					Mulloch Hill.
,, elongatus (*Portlock*)				×				Thraive Glen.
,, Argo (*Billings*)? ..				×				Thraive Glen.
					×			Shalloch Mill.
,, sp.	×							Penkill.
sp.		×						Newlands, Woodland Point.

	U. Llandovery.	M. Llandovery.	L. Llandovery.	Upper Bala.	Middle Bala.	Lower Bala.	Llandeilo.	
HETEROPODA—*continued.*								
Bellerophon sp.					×			Shalloch Mill.
,, sp.							×	Balclatchie conglomerate.
,, sp.							×	Craighead, Ardmillan, Balclatchie, Dow Hill.
Maclurea magna (*Lesueur*)							×	Aldons, Tramitchell, Minuntion.
,, matutina (*Hall*) ?							×	Balclatchie conglomerate.
,, Logani (*Salter*)							×	Craighead.
,, macromphala (*M'Coy*)							×	Craighead.
CEPHALOPODA.								
Orthoceras politum (*M'Coy*)						×		Pinmore, Waterfall Penwhapple Glen.
,, Avelini (*Salter*)							×	Ardmillan.
,, bilineatum (*Hall*)					×		×	Craighead.
,, arcuoliratum (*Hall*)					×			Shalloch Mill.
,, ludense (*Sow.*)					×			Shalloch Mill.
				×				Thraive Glen.
,, vagans (*Salter.*)					×			Shalloch Mill.
				×				Thraive Glen.
,, tenuicinctum (*Portl.*)			×					Mulloch Hill, Rough Neuk.
		×						Woodland Point.
,, distans (*Sow.*)		×						Woodland Point.
				×				Starfish Bed.
,, imbricatum (*Wahl.*)			×					Mulloch Hill, Rough Neuk, High Road Quarry.
		×						Woodland Point.
	×							Penkill, Cuddystone Glen.
,, tracheale (*Sow.*)		×						Woodland Point.
,, mocktreense (*Sow.*)		×						Woodland Point.
,, bullatum (*Sow.*)					×			Whitehouse Bay.
		×						Woodland Point.
,, primævum (*Forbes*)	×							Penkill.
				×				Thraive Glen.
,, angulatum (*Wahl.*)			×					Mulloch Hill, Ptilograptus Bed.
		×						Woodland Point, Newlands.
	×							Penkill.
,, Bacchus (*Barr.*)	×							Penkill, Bargany Pond Burn.
	×							Penwhapple Glen, Penkill Beds.
,, annulatum (*Sow.*)	×							Penwhapple Glen.
,, Grindrodi (*Blake*)	×							Penkill Beds, Penwhapple Glen.
,, fusiforme (*Hall*) ?	×							Penkill, Penwhapple Glen.
,, multicinctum (*Hall*)	×							Penkill.
,, sp.	×							Camregan Wood.
,, gracile (*Portlock*)					×			Shalloch Mill.
,, subundulatum (*Portl.*)							×	Dow Hill.
,, sp.				×				Thraive Glen.
Phragmoceras arcuatum (*Sow.*)			×					Mulloch Hill, Rough Neuk.
,, sp.		✓						Woodland Point.
,, sp.							×	Balclatchie conglomerate.
Endoceras proteiforme, var. strangulatum (*Hall*)				×			×	Thraive Glen. Balclatchie, Dow Hill.
Gomphoceras sp.	×							Penkill.
,, crater (*Blake*)		×						Woodland Point.
,, cinctum (*Blake*)	×							Camregan Wood.
Poterioceras sp.	×							Penkill.
Cyrtoceras victor (*Barr.*) ?				×				Starfish Bed.
,, arcuatum (*Hall*)		×						Woodland Point.
,, sp.							✓	Craighead.
,, sp.							×	Balclatchie conglomerate.
,, compressum (*Sow.*)	×							Penkill.
,, scoticum (*Blake*)							✓	Craighead, Minuntion.
,, annulatum (*Hall*)			×					Mulloch Hill, Rough Neuk.
,, sp.							✓	Minuntion.
Oncoceras sp.			×					Mulloch Hill.
,, sp.		×						Woodland Point.
,, sp.		×						Newlands.
Trocholites planorbiformis (*Conrad*)							×	Craighead
,, cornuarietis (*Sow.*)			×					Mulloch Hill, Rough Neuk.
Trochoceras aspersum (*Barr.*) ?		×						Woodland Point.

No. 4.—Complete List of Fossils from the Stinchar Limestone Series (Upper Llandeilo) of the Girvan District of the South of Scotland.

Algæ. (?)

Girvanella problematica (*Nich. & Eth.*)

Rhizopoda?

Nidulites favus (*Salter*).

Foraminifera.

Saccammina Carteri (*Brady*).

Hydrozoa.

Cryptograptus tricornis (*Carr.*)
Clathrograptus cuneiformis (*Lapw.*)
Climacograptus bicornis (*Hall*).
,, nanus.
,, Schärenbergi (*Lapw.*)
Dicellograptus sextans (*Hall*).
,, sp.
Dicranograptus ramosus (*Hall*).
,, sp.
Didymograptus superstes (*Lapw.*)
,, sp.
Diplograptus foliaceus (*Murch.*)
,, rugosus (*Emm.*)
,, sp.
Glossograptus Hincksi (*Hopk.*)

Cœlenterata.

Actinozoa.

Chætetes (*Fischer*).
Favosites girvanensis (*Nich. and Eth.*)
Fistulipora pilula (*Nich. and Eth.*)
Halysites sp.
Heliolites Grayi (*Edw. and Haime*).
Labechia canadensis (*N. and Murie*).
Lindströmia subduplicata (*M'Coy*).
Lyopora favosa (*M'Coy*).
Monticulipora girvanensis (*Nich.*)
Petraia elongata (*Phil.*)
Prasopora Grayæ (*Nich. and Eth.*)
Propora Edwardsi (*Nich. and Eth.*)
Stenopora fibrosa (*Goldf.*)
Streptelasma æquisulcatum (*M'Coy*).
,, aggregatum (*N. and E.*)
,, craigense (*M'Coy*).
,, europæum (*Röm.*)
Stylarœa occidentalis (*Nich. and Eth.*)
Tetradium Peachi (*Nich. and Eth.*)
Thecostegites scoticum (*Nich. and Eth.*)

Crinoidea.

Glyptocrinus (*Hall*) sp.

Annelida.

Cornulites (*Schl.*) sp.
Serpulites longissimus (*Murch.*)

Cirripedia.

Turrilepas (*Woodw.*) sp.

Ostracoda.

Cythere aldensis (*M'Coy*).
,, ,, var. major (*Jones*).
,, grayana (*Jones*).
,, wrightiana (*Jones and Holl.*)
Primitia barrandiana (*Jones*).

Trilobita.

Ampyx (*Dalm.*) sp.
Asaphus (Isotelus) gigas (*Dekay*).
,, ,, rectifrons (*Portl.*)
Bronteus (*Goldf.*) sp.
Calymene Blumenbachi (*Brong.*)
Cheirurus bimucronatus (*Murch.*)
,, gelasinosus (*Portl.*)
Dindymene (*Corda.*) sp.
Encrinurus punctatus (*Brün.*)
,, ,, var. arenaceus (*Salt.*)
,, ,, var. calcareus (*Salt.*)
Harpes (*Goldf.*) sp.
Illænus (Dysplanus) æmulus (*Salt.*)
,, ,, Bowmani (*Salt.*)
,, ,, latus (*M'Coy*).
,, Portlocki (*Salt.*)
,, sp.
Lichas hibernicus (*Portl.*)
Phacops Brongniarti (*Portl.*)
Remopleurides Barrandei (*Eth. & Nich.*)
,, Colbii (*Portl.*)
,, laterispinifer (*Portl.*)
,, sp.
Sphærexochus mirus (*Beyr.*)
Trinucleus (*Lhwyd*). sp.

Brachiopoda.

Acrotreta Nicholsoni (*Dav.*)
Crania siluriana (*Dav.*)
,, sp.
Discina perrugata (*M'Coy*).
Leptæna Etheridgei (*Dav.*)
,, Grayi (*Dav.*)
,, llandeiloensis (*Dav.*)
,, (Plectambonites) quinquecostata (*M'Coy*).

BRACHIOPODA—*continued.*

,, sericea (*Sow.*)
,, ,, var. rhombica (*M'Coy*).
,, (Christiania) tenuicincta (*M'Coy*).
,, (Plectambonites) transversalis (*Wahl.*)
,, youngiana (*Dav.*)
Lingula attenuata (*Sow.*)
,, granulata (*Phil.*)
,, ovata (*M'Coy*).
,, quadrata (*Eichw.*)
,, Ramsayi (*Salt.*)
Meristella angustifrons ? (*M'Coy*).
Nucleospira pisum (*Sow.*)
Orthis balcletchiensis (*Dav.*)
,, (Platystrophia) biforata (*Schl.*)
,, calligramma (*Dalm.*)
,, ,, var. virgata (*Salt.*)
,, ,, var. scotica (*Dav.*)
,, confinis (*Salt.*)
,, crispa (*M'Coy*).
,, (Dalmanella) elegantula (*Dalm.*)
,, (Dinorthis) flabellulum (*Sow.*)
,, girvanensis (*Dav*)
,, intercostata (*Portl.*)
,, protensa (*Sow.*)
,, sowerbyana (*Dav.*)
,, (Dalmanella) testudinaria (*Dalm.*)
,, turgida (*M'Coy*).
,, unguis (*Sow.*)
,, vespertilio (*Sow.*)
Rhynchonella æmula (*Salt.*)
,, balcletchiensis (*Dav.*)
,, Lapworthi (*Dav.*)
,, nasuta (*M'Coy*).
,, Peachi (*Dav.*)
,, (Hyattella) portlockiana (*Dav.*)
,, Salteri (*Dav.*)
,, scotica (*Dav.*)
,, sub-borealis (*Dav.*)
,, Thomsoni (*Dav.*)
,, Weaveri (*Salt.*)
Siphonotreta anglica (*Morris*).
,, micula (*M'Coy*).
,, scotica (*Dav.*)
Strophomena corrugatella (*Dav.*)
,, (Rafinesquina) deltoidea (*Conr.*)
,, (Rafinesquina) expansa (*Sow.*)
,, Grayi (*Dav.*)
,, imbrex (*Pand.*), var. semiglobosa (*Dav.*)
,, llandeiloensis (*Dav.*)
,, retroflexa (*Salt.*)
,, (Leptæna) rhomboidalis (*Wilck.*)
,, sp.

BRACHIOPODA—*continued.*

Triplesia Grayæ (*Dav.*)
,, sp.

LAMELLIBRANCHIATA.

Ambonychia amygdalina (*Hall*).
,, radiata (*Emm.*)
Orthonota contracta (*Hall*).
Pleurorhynchus dipterus (*Salt.*)

GASTEROPODA.

Bellerophon acutus (*Sow.*)
,, punctifrons (*Emm.*)
,, sp.
,, (Bucania) profunda (*Hall*).
Chelodes (*Dav. and King*).
,, (Helminthochiton) sp.
Cyrtolites (*Conrad*) sp.
Ecculiomphalus Bucklandi (*Portl.*)
,, lævis (*Sow.*)
,, sp.
Holopea paludiniformis (*Hall*).
Maclurea Logani (*Salt.*)
,, (Ophileta) macromphala (*M'Coy*).
,, Maccoyi (*Salt.*)
,, magna (*Lesu.*)
,, matutina (*Hall*).
Macrocheilus (*Phillips*) sp.
Metoptoma (*Phil.*) sp.
,, (Tryblidium) sp.
Murchisonia angulata (*Sow.*)
,, (Pleurotomaria) bicincta (*Hall*).
,, gracilis (*Hall*).
,, gyrogonia (*M'Coy*).
,, vitellia (*Bill.*)
Ophileta (*Vanux*) sp.
Pleurotomaria (*Defr.*)
,, (Raphistoma) lenticularis (*Sow.*)
,, qualteriata (*Schl.*)
Platyceras (*Conr.*) sp.

PTEROPODA. (?)

Conularia elongata (*Portl.*)
,, Sowerbyi (*Defr.*)
Hyolithes (*Eichw.*) sp.
Theca (*Sow.*) sp.

CEPHALOPODA.

Cyrtoceras inæquiseptum (*Portl.*)
,, multicamaratum (*Hall*).
,, scoticum (*Blake*).
,, sp.
Orthoceras bilineatum (*Hall*).
,, pendens (*Blake*).
,, politum (*M'Coy*).
,, sp.
Trocholites planorbiformis (*Conrad.*)

No. 5.—Comparative Table of Fossils from the Caradoc Rocks of Balclatchie, Leadhills, Wallace's Cast, Kilbucho, Glencotho, Wrae, and Winkston.

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
Rhizopoda?							
Cyclocrinus (*Eichwald*)							
,, sp.			×				
Nidulites (*Salter*)							
,, favus (*Salt.*)	×	×	×	×			
Spongida.							
Ischadites (*Murchison*)							
,, Kœnigi (*Nich. and Eth.*)	×						
Hydrozoa.							
Dicranograptus (*Hall*)							
,, tardiusculus (*Lapw.*) ...	×						
Dicellograptus (*Hopkinson*)							
,, moffatensis (*Carr.*)	×						
Diplograptus (*M'Coy*)							
,, rugosus (*Emm.*)...	×						
Climacograptus (*Hall*)							
,, Schärenbergi (*Lapw.*) ...	×						
Actinozoa.							
Alveolites (*Lamarck*)							
,, sp.			×				
Favosites (*Lamarck*)							
,, asper (*D'Orb.*)	×						
,, cristatus (*Blum.*)							×
,, gothlandicus (*Fougt*)				×			
,, sp.			×				
Fistulipora (*M'Coy*)							
,, favosa (*Nich. and Eth.*)	×						
Heliolites (*Dana*)							
,, sp.			×				
Lindströmia (*Nicholson and Thomson*)							
,, subduplicata (*M'Coy*)			×	×			
,, ,, var. crenulata (*M'Coy*) ...				×			
Lyopora (*Nicholson and Etheridge*)							
,, favosa (*M'Coy*)				×			
Monticulipora (*D'Orbigny*)							
,, lens (*M'Coy*)		×					
Palæocyclus (*Edwards and Haime*)							
,, sp.			×	×			

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
ACTINOZOA—*continued.*							
Petraia (*Münster*)							
,, bina (*Lonsd.*)		×	×	×			
,, elongata (*Phil.*)...		×					
,, uniserialis (*M'Coy*)		×		×			
,, zic-zac (*M'Coy*)...			×				
Stenopora (*Lonsdale*)							
,, (Favosites) fibrosa (*Goldf.*) ...		×	×	×			
Syringophyllum (*Edwards and Haime*)							
,, (Sarcinula) sp.			×				
Tetradium (*Dana*)							
,, sp.			×				
CRINOIDEA.							
Glyptocrinus (*Hall*)							
,, basalis (*M'Coy*)		×	×	×	×	×	×
,, sp....	×	×		×	×	×	×
Myelodactylus (*Hall*)							
,, sp.	×						
Crinoid stems.	×	×		×	×	×	×
ANNELIDA.							
Serpulites (*M'Leay*)							
,, longissimus (*Murch.*)			×				
Tentaculites (*Schlotheim*)							
,, sp.	×						
CIRRIPEDIA.							
Turrilepas (*Woodward*)							
,, scotica (*Nich. and Eth.*)	×						
,, sp.							×
PHYLLOCARIDA.							
Pinnocaris (*Etheridge, jnr.*)							
,, Lapworthi (*Eth., jnr.*)	×						
Peltocaris (*Salter*)							
,, (?) sp....	×						
TRILOBITA.							
Acidaspis (*Murchison*)							
,, Grayæ (*Eth., jnr.*)	×						
,, hystrix (*Wyv.-Thom.*)	×						
,, Lalage (*Wyv.-Thom.*)	×						
Agnostus (*Brongniart*)							
,, agnostiformis (*M'Coy*)	×						
Ampyx (*Dalman*)							
,, Hornei (*Eth. and Nich.*)	×						
,, Maccallumi (*Salt.*)	×						
,, mammilaris (*Sars*)	×						
,, rostratus (*Sars*)	×						
,, sp.	×						
Asaphus (*Brongniart*)							
,, (Isotelus) gigas (*Dekay*)	×						
,, ,, rectifrons (*Portl.*) ...	×						
,, sp.					×		

	Balclatchie.	Leadhills.	Wallace's Oast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
TRILOBITA—*continued.*							
Barrandia (*M'Coy*)							
,, sp.	×						
Bronteopsis (*Wyville-Thomson*)							
,, scotica (*Salt.*)	×						
Bronteus (*Goldfuss*)							
,, Andersoni (*Eth. and Nich.*) ...	×						
Calymene (*Brongniart*)							
,, sp.		×					
Cheirurus (*Beyrich*)							
,, bimucronatus (*Murch.*)	×						×
,, clavifrons (*Dalm.*)				×			
,, gelasinosus (*Portl.*)	×						×
,, Sedgwicki (*M'Coy*)	×						
,, sp.	×	×				×	×
Cybele (*Lovén*)							
,, verrucosa (*Dalm.*)	×						
,, sp.	×						
Deiphon (*Barrande*)							
,, Forbesi (*Barr.*)	×						
Harpes (*Goldfuss*)							
,, parvulus (*M'Coy*)						×	
,, sp.	×						
Homalonotus ? (*Kœnig*)							
,, sp....		×					
Illænus (*Dalman*)							
,, (Dysplanus) Bowmani (*Salt.*) ...	×					×	×
,, Davisi, var. B. involutus (*Salt.*) ...						×	
,, (Dysplanus) latus ? (*M'Coy*) ...			×				
,, ,, Thomsoni (*Salt.*) ...	×						
,, young of...					×		
,, sp.	×						
Lichas (*Dalman*)							
,, Grayi (*Fletch.*)	×						
,, hibernicus (*Portl.*)	×						
,, sp.	×						
Ogygia (*Brongniart*)							
,, sp.		×					
Phacops (*Emmrich*)							
,, (Acaste) alifrons (*Salt.*)				×	×		
,, ,, Brongniarti (*Portl.*) ...	×		×	×			
,, (Dalmanites) caudatus ? (*Brünn.*) ...		×		×			
Proetus (*Steininger*)							
,, girvanensis (*Eth. and Nich.*)... ...	×						
Remopleurides (*Portlock*)							
,, Barrandei (*Eth. and Nich.*) ...	×						
,, Colbii (*Portl.*)			×				
,, laterispinifer (*Portl.*)... ...	×		×				
,, nov. sp.			×				
Salteria (*Wyville-Thomson*)							
,, primeva (*Wyv.-Thom.*)	×						
Sphærexochus (*Beyrich*)							
,, mirus (*Beyr.*)	×				×	×	×
Staurocephalus (*Barrande*)							
,, globiceps (*Portl.*)	×						

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
TRILOBITA—*continued.*							
Staurocephalus unicus (*Wyv.-Thom.*) ...	×						
Stygina (*Salter*)							
,, latifrons (*Portl.*)	×						
Trinucleus (*Lhywd*)							
,, concentricus (*Eaton*)	×						
,, fimbriatus (*Murch.*)		×					
,, Macconochiei (*Eth. and Nich.*) ...	×						
,, ornatus (*Sternb.*)	×						
,, sp.				×			
POLYZOA.							
Ceriopora (*Goldfuss*)							
,, oculata (*Goldf.*)				×			
Fenestella (*Lonsdale*)							
,, sp.		×					
Ptilodictya (*Lonsdale*)							
,, costellata (*M'Coy*)				×			
,, dichotoma (*Portl.*)...	×	×	×				
,, sp.			×				
Retepora (*Lamarck*)							
,, sp.	×		×				
Sulcoretepora (*D'Orbigny*)							
,, sp.			×				
BRACHIOPODA.							
Acrotreta (*Kutorga*)							
,, costata ? (*Dav.*)	×						
,, Nicholsoni (*Dav.*)	×						
Crania (*Retzius*)							
,, sp.	×						
Discina (*Lamarck*)							
,, oblongata (*Portl.*)	×						
,, perrugata (*M'Coy*)	×					×	×
,, sp.					×	×	
Leptæna (*Dalman*)							
,, (Plectambonites) quinquecostata (*M'Coy*)	×						×
,, scissa = llandeiloensis (*Dav.*) ...	×			×			
,, sericea (*Sow.*)	×	×	×	×	×		×
,, ,, var. rhombica (*M'Coy*) ...	×	×	×				
,, (Christiania) tenuicincta (*M'Coy*) ...	×	×	×	×			
,, (Plectambonites) transversalis (*Wahl.*)			×	×		×	×
,, youngiana (*Dav.*)	×						
,, sp.					×		
Lingula (*Bruguière*)							
,, attenuata (*Sow.*)	×		×		×	×	×
,, brevis (*Portl.*)	×						
,, canadensis (*Bill.*)	×						
,, granulata (*Phil.*)	×						
,, longissima (*Pand.*)						×	
,, ovata (*M'Coy*)	×						
,, Ramsayi (*Salt.*)	×						×
Meristella (*Hall*)							
,, (Whitfieldia) tumida (*Dal.*) ...					×		×

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
BRACHIOPODA—*continued.*							
Meristina (*Hall*)							
,, (= Whitfieldia (*Sow.*)							
,, (Meristella) tumida (*Dalm.*) ...					×		×
Obolella or Kutorgina (*Billings*)							
,, sp.							×
Orthis (*Dalman*)							
,, Actoniæ (*Sow.*)					×	×	×
,, (Platystrophia) biforata (*Schl.*) ...		×			×		
,, (Bilobites) biloba (*Linn.*)							
,, Bouchardi, var. balcletchiensis (*Dav.*)	×						
,, calligramma (*Dalm.*)		×	×	×	×	×	×
,, ,, var. plicata (*Sow.*) ...	×						
,, ,, var. virgata (*Salt.*) ...	×						
,, Carausii (*Salt.*)	×						
,, crispa (*M'Coy*)	×	×	×	×			
,, (Dalmanella) elegantula (*Dalm.*) ...	×		×				
,, (Dinorthis) flabellulum (*Sow.*)				×			
,, girvanensis ? (*Dav.*)	×						×
,, Lapworthi (*Dav.*)	×						
,, polygramma (*Sow.*)							
,, ,, var. pentlandica (*Dav.*) ...	×	×					
,, protensa (*Sow.*)				×			
,, Rankini (*Dav.*)							
,, rustica (*Sow.*)				×			
,, sowerbyana (*Dav.*)	×				×	×	×
,, (Dalmanella) testudinaria (*Dalm.*) ...	×	×	×				
,, turgida (*M'Coy*)	×						
,, unguis (*Sow.*)				×			
,, vespertilio (*Sow.*)			×				
,, sp.			×				×
Paterula (*Davidson*)							
,, (Discina) balcletchiensis (*Dav.*) ...	×						
Porambonites (*Pander*)							
,, intercedens (*Pand.*)					×		
,, sp.					×		
Rhynchonella (*Fischer*)							
,, ardmillanensis (*Dav.*)	×						
,, balcletchiensis (*Dav.*)	×						
,, borealis (*Schl.*)			×				
,, cuneatella (*Dav.*)	×						
,, girvanensis (*Dav.*)	×						
,, Jacki (*Dav.*)		×					
,, maccoyana (*Dav.*)					×		
,, nasuta (*M'Coy*)	×						
,, nucula (*Sow.*)	×						
,, Stricklandi (*Sow.*)			×				
,, sp.	×		×				
Siphonotreta (*De Verneuil*)							
,, micula (*M'Coy*)							×
Stricklandinia (*Billings*)							
,, balcletchiensis (*Dav.*)	×						
trophomena (*Rafinesque*)							
,, arenacea (*Salt.*)		×					
,, compressa (*Sow.*)	×						

	Balclatchie.	Leadhills.	Wallace's Cast.	Kilbucho.	Glencotho.	Wrae and Drummelzier.	Winkston and Hamilton Hill.
BRACHIOPODA—*continued.*							
Strophomena corrugatella (*Dav.*)	×	×	×				
,, (Rafinesquina) deltoidea (*Conr.*)	×						×
,, ,, var. rotundata (*Conr.*) ...			×				
,, ,, var. expansa (*Sow.*) ...	×	×					
,, grandis (*Sow.*)		×	×				
,, imbrex (*Pand.*)	×						
,, (Orthis) kilbuchoensis (*Dav.*) ...	×		×	×			
,, llandeiloensis (*Dav.*)	×						
,, retroflexa (*Salt.*)...	×						
,, (Leptæna) rhomboidalis (*Wilck.*)	×		×	×			
,, semiglobosina (*Dav.*)	×						
,, shallockiensis (*Dav.*)	×						
,, sp.	×			×			×
Triplesia (*Hall*)							
,, spiriferoides ? (*M'Coy*)	×						
,, sp.							×
LAMELLIBRANCHIATA.							
Ambonychia (*Hall*)							
,, radiata (*Emmons*)	×						
,, sp.	×						
Arca (*Linnæus*)							
,, edmondiæformis (*M'Coy*)	×						
Avicula (*Klein*)							
,, sp.	×						
Ctenodonta (*Salter*)							
,, anglica (*D'Orb.*)	×						
,, astarteformis (*Salt.*)	×						
,, levata (*Hall*)	×		×				
,, (Nucula) subacuta (*M'Coy*) ...	×						
,, varicosa (*Salt*)	×						
,, sp.	×	×	×				
Cucullella (*M'Coy*)							
,, sp.			×				
Goniophora (*Phillips*)							
,, sp.	×						
Modiolopsis (*Hall*)							
,, modiolaris (*Conrad*)	×						
,, orbicularis (*Sow.*)...			×	×			
,, sp.		×	×				
Orthonota (*Conrad*)							
,, undata ? (*Sow.*)					×		
Pleurorhynchus (*Phillips*)							
,, (Conocardium) dipterus (*Salt.*)	×						
GASTEROPODA.							
Bellerophon (*Montfort*)...							
,, acutus (*Sow.*)	×	×	×				
,, bilobatus (*Sow.*)	×						
,, dilatatus (*Sow.*)			×				
,, expansus (*Sow.*)	×						
,, trilobatus (*Sow.*)	×	×					

Clenries, Sanquhar, 299.
Clackleith, 319, 320.
Clanyard Bay, 183.
—— —— fossils from, 184, 185, 189.
Clenoch Burn, 171.
Clerk, Mr., of Eldin, 5.
Clinking Cove, 553, 555.
Clints Farmhouse, 271.
Cloderroch, 347.
— Burn, 348, 384.
Clough, C. T., 73.
Clovenfords, 203, 205.
Clowgill, 281.
Clyde, R., 280, 327.
Coal Burn, Sanquhar, 301.
—— Heugh, Tarff Water, 172, 213.
Cockburnspath, 208, 209.
Cocker Hill, 311.
Cog Burn, 297.
Cogshead, 297.
Coldchapel Burn, 227.
Cold Grain, 138.
Coldshiels Loch, 191, 202.
Colfin, 408.
—— Glen, 408.
Collie Law, 261.
Colmonell, 452, 453, 466, 468, 476, 481, 499, 500.
Colvend shore, 554.
Cone Gill, 280.
Conglomerate, Afton Water, 385.
— Auchencally, 385.
— Benan, 82, 485.
— Corsewall Point, 82, 410.
—— —— pebbles in, 410.
—— Craigenputtock, 214.
—— Duntercleugh, 82, 323, 324.
—— March Burn, 384.
— Snar Water, 294.
—— with Highland boulders, 277.
Connel Burn, 374.
—— —— Rig, 374.
Conrig Burn, Sanquhar, 298.
—— Hill, 299, 301.
Conrick Burn, 339.
— Hass, 339.
Contact-metamorphism, 632.
Coomb Dod, 232.
Coom Gill, Glengonner Water, 283.
Copper, 655.
—— ore at Balkeachy, 459.
Coquet Head, 562.
Corbie Burn, 202.
Corfardine, 347, 348.
Cormilligan, 384.
Corrie Water, 557.
Corrodow slates, 384.
Corsebank, 303, 318, 371.
Corsehill, Kirkcudbrightshire, 168.
Corsehope, 270.
Corsewall Lighthouse, 410, 415.
—— conglomerate, 410.
—— Point, 401, 410, 415, 507.
Corsock, 156, 161.
Cossarshill Burn, 111.
Cow Gill, 235, 238.
Cowie's Linn Burn, Eddleston, 252.
Cow Linn, Fruid Water, 142, 144.
Craigbickerae Hill, 485.
Craigbuie Hill, 337.
Craigdarroch, 349.
— Afton Water, 385.
Craigdasher Hill, 157.
Craig Dod, 283, 285.
Craigenputtock conglomerate, 214.
—— —— quartzite and quartz-schist-pebbles in, 214.
—— Hill, 214.
Craigierig, 140.
Craigenterrie inlier, 605.
Craighead, 462, 501, 502, 508, 523, 527.
—— Hill, 462, 463, 501.
inlier, Caradoc rocks of, 522.
— limestone, 83, 462.
—— —— horizon of, 502.
—— Quarry, 462.
—— Upper Silurian of, 528.
Craig Hill, R. Stinchar, 453, 454.
—— —— Farm, 454.
Craighouse, Duneaton Water, 327.
Craighope Burn, 266.
Craiglure Lodge, 416, 418, 419.
Craigmichan Scaurs, 100–105.
—— —— fossil lists from, 103, 104.
—— —— Rae Grain plan, 102.
—— —— —— section, 104.
—— —— section, 101.
—— —— radiolarian chert in, 103.
Craignair Quarry, 609.
Craigneil, 451, 453,
—— Castle, 476, 494, 498, 499.
—— Farm, 499.
Craignorth Burn, 320.
—— Hill, 303, 318, 320.
Craig of Knockgray, 385.
Craigrarson, 616.
Craigskelly, 519, 527, 542.
Craigwells, 491, 493, 506.
— Cottage, 491.
Craigy Cleugh, Cogs Burn, 297.
Crailloch, Stranraer, 410.
— Burn, Stranraer, 409.
—— Hill, Stranraer, 410.
—— Water of Mailzie, 174, 177, 178.
Crailzie Hill, 252.
Crairieknowe, 334.
Cramalt, 140.
Crawick Water, 303, 313.
Crawfordjohn, 303, 321, 327.
Cree River, 172, 213, 387, 390, 396, 419.
Creetown granite, 624.
—— Station, 172.
Criffel, 552.
—— and Dalbeattie granite, 607-610.
Crogo Burn, Auchenvey, 161.
—— Tower, 159, 160.
Crook, R. Tweed, 142.
—— Burn, Daer Water, 155.
Crookmill Burn, 269.
Croseclays, 448, 471.
Crossmichael, 164, 169, 170.
Crossopodia shales, 545.
Cross Water, Barrhill, 417.
—— —— of Luce, 399, 401.
Crow's Burn, Bladenoch R., 179.
—— Nest, Glenluce, 102, 183.
Cuddystone Burn, 540.
Culcaigrie Hill, 213.
Culmark, 346.
Culroy, 180, 182.

Culshabben School, 177.
Culter Water, 232, 235, 240, 244, 249.
—— Waterhead, 232.
Cundry Mill, 457, 458.
Cunningham, R. Hay, 7.
—— —— Geology of the Stewartry of Kirkcudbright, 7.
Curlywee, 387, 395, 419.
Currarie, Ballantrae, 424, 426, 427, 506, 507.
—— Burn, 424.
—— Glen, 421, 424.
—— Port, 424, 426.
Cyrtograptus Grayi mudstones, 81, 545, 546.

D

Daer Water, 155.
Dailly series, 544.
Dairon, W., 26.
Dakyns, J. R., 73.
Daldowie, Llandeilo-Caradoc rocks, 511.
—— Hill, 460, 491, 493, 511.
—— —— volcanic area of, 460.
Dalfarson, 372.
Dalgonner Burn, 358.
Daljarrock, 453, 454, 494.
—— limestone quarry, 469.
Dalleagles Burn, 375.
—— galena, 654.
Dally Bay, 507.
Dalmellington district, 371.
Dalpeddar, 331.
Dalry, Galloway, 199, 213, 333, 347, 350.
Dalshangan, R. Ken, 333, 343, 344, 345.
Dalveen group, 211.
—— Pass, 155, 200.
Dalwhat Water, 339-341, 383, 384.
Dalzean Burn, 337.
Dana, Professor, 468.
Darley, 463.
Darn Hall, 251.
Davidson, Thomas, 17, 324, 502, 596.
—— —— Brachiopoda of the Pentland Hills, 17.
—— —— Brachiopoda of Girvan, 27.
—— Monograph of the Silurian Brachiopoda, 27.
Deaf Heights, 196, 205.
Deafstone Farm, 476.
Deerhope Burn, 597.
—— Rig, 600.
Dee, River, 170, 171, 215.
—— —— and Nith, Wenlock and Ludlow rocks between, 552.
—— Loch, 387.
Deil's Barn Door, 220, 222, 231, 233.
Deloraine, 211.
—— Burn, 212.
Demster's, Glenmuckloch, 368.
Dendrograptus from Knockgown, Ballantrae, 429.
—— Portandea, 422.
—— Snar Water, Crawfordjohn, 321.
Deuchric Farmhouse, 279.
Deugh Water, 343, 344, 375, 377, 378, 383, 385.
—— black shale bands, 376.
Dewar Water, 194.
Diabase-lava, 84.
—— analysis of, 85.
—— pillowy structure of, 84, 85, 86.
Diabase-porphyrite, 84, 87.
—— —— of Currarie, 428, 449.
—— schistose, 228.
Diallage, 475.
Dibbin Lane section, 339, 340, 341, 342.
Dicellograptus anceps at Drummuck, 82, 524.
—— *complanatus* zone, Girvan, 82, 518.
—— —— Lammermuirs, 279.
Dictyonema zone, 518.
Didymograptus shales (Barr series), 83, 487, 488, 489.
Dimple, 239.
Dinvin Hill, 500.
Dionide beds, 518.
Diorite dykes, 628.
—— of Kirkcowan, 624.
Diplograptus modestus shales, 534.
Dippal Burn, 577.
Dirneark, 398, 399.
Dobb's Linn typcal section, 92-100.
—— —— ground plan of, 93.
—— —— fossil lists from, 95, 100.
—— —— sections, 94, 95, 96, 98.
—— —— radiolarian chert zone, 99.
Dolerite, 91.
Doon Loch, Wigtownshire, 176.
—— —— Ayrshire.
Dormont House, 558.
Dornell Hills, 213.
Doresford, 562.
Dougaries, 401.
Douglas Burn, Yarrow, 141.
—— Water, Lanarkshire, 582, 585.
Dounan, Portpatrick shore, 411, 412.
—— —— hæmatite vein at, 411.
—— —— shales, 412.
Doune, 501.
Dove Cave Bay, Llandovery rocks, 187, 188.
—— Cove, Knock Bay, Portpatrick, 415.
—— —— Currarie, Ballantrae, 430, 431.
Dow Hill.
—— Bennan conglomerate, 501.
—— Balclatchie mudstones, 514.
—— —— fossils from do., 514.
Downan, Ballantrae.
—— —— pillow-lava at, 431.
—— Point, Ballantrae, 426, 430, 431.
Downtonian, 68, 69, 80.
—— conditions of deposition, 68.
—— fish fauna, 68, 565–567.
—— fossils of, 68, 69.
—— series, 576, 583, 599.
—— sub-divisions of, 68, 569.
Drakestruther Burn, Lauderdale, 197.
Druidhill Burn, 336.
Druim nan Eidne, Skye, 477, 478.
Drochil Castle, 251, 252.
Drumbreddan Bay, 185, 186.
—— —— fossils from, 186, 189.
Drumabrennan, 391, 392, 420.

Drumbreddan School, 392.
Drumblair, 174, 176.
Drumfairn Farmhouse, 498.
Drumglass, 213.
Drumlawhinnie, 173.
Drum Maw Hill, 251.
Drummelzier, 258.
—— fossils from Caradoc rocks, 257.
Drummore, Wigtownshire, 216.
—— Burn, Ballantrae, 471.
Drummuck, 504, 523, 528.
—— group, 524.
Dicellograptus anceps from, 524.
Drummpail, 393.
Drumyork flagstones, Tarannon, 81, 544.
Dry Cleugh, 285.
Dryfe Water, 213.
Dryhope Hope, 140.
Duffkinnel Water, 150.
Duisk R., 417.
Dunlarg, 490.
Duncan Gill, 233.
—— —— Head, 233.
Dundrennan, 552.
Duneaton Water, 327, 328.
Dunniewick, 481.
Dunite, 468.
Dunannee, black shales at, 170.
—— and fossils from, 170.
Dunragit, 387, 394, 395.
Dunrod Burn, 555.
Dunscore, 156.
Dunside, 574, 575.
Duntercleugh, 227, 243, 251, 289, 291, 321.
—— Burn, 292.
—— conglomerate, 82, 323.
—— —— fossils from, 324.
—— grit, 320, 321.
—— Rig, 324.
Dupin, 491, 493.
—— Mid Burn, 492.
—— East Burn, 492.
—— Farm, 492.
—— Glen, 492.
Dyke Farmhouse, 550.
Dykes, 625.

E

Earnscleugh, 206.
—— Burn, Lauderdale, 196.
East Burn, Lammer Law, 275.
Easter Burn, Blythe Burn, 207.
Eastern Highlands, pebbles from, 210.
Eastside Burn, Culter Water, 233.
East Mains Hill, 240, 241.
Economic products, 652.
Eddleston, 251.
—— Water, 252, 263.
Edgerston Burn, 561.
Elder Burn, 366.
Eldinhope Burn, 113.
Eldrig Loch, Mochrum, 180.
—— —— Tarff Water, 399.
Eller Scaur, Crawick Water, 319.
Elvanfoot, 155, 199, 200, 332.
Elvan Water, 328.
Emly Bank, 267.
Enterkin Burn, 331.
Enterkinfoot, 199, 332, 383.
Entertrona, 116, 121.
Epidiorites, 91.
Ernerogo Loch, 169, 170.
Eskdalemuir, 213.
Esk, Pentland Hills, section, 596–599.
Etheridge, R., junior, 27, 28, 503.
—— —— senior, 347.
Ettrickbridge-end, section, 121–128.
Ettrick Pen, 211, 213.
—— River, 212.
Euchan Water, 351, 355, 364, 365, 386.
Ewe Hill, 361, 362.
Ewes Water, Langholm, 558.
—— —— Lugate Water, 196.
Eyan Water, Moffat, 211.
Eyemouth, 209.

F

Fair Burn, Camps Water, 232.
Fairydean Burn, 251.
Falbogue Bay, 215, 553.
Faldonsidemoor, Melrose, 207.
Farden Farmhouse, 523.
Fardingmulloch, 333, 334.
Fast Castle, 209.
Fauldribban Hill, 522.
Fault, Glen App, 411, 507.
Fell Hill, 454.
Felsite-soda, 53, 88, 89, 257, 258, 260.
—— analysis of, 88, 89.
—— perlitic, 53, 89, 261.
Fernie Burn, Sit Burn, 195.
Fingland Burn, Sanquhar, 298, 299.
—— —— Spango Water, 326, 327.
Finnart Holm, R. Stinchar, 450, 452.
Fish beds (Downtonian), 577.
Fish fauna of Upper Silurian, 565.
Fish House, Glenluce, 182, 183.
Flaser-epidote rocks, Carlton Hill, 456, 457.
—— —— —— Lochton, 458.
Fleet, Little Water of, 172.
Flett, J. S., 624.
Fleming, Mr., 8, 556.
Flemington Burn, 250.
Flint Hill, 246, 247.
Feoch Burn, 416.
Fountainhall, 190, 194.
Fox Howard, 470.
Frenchland Burn, 130.
Friar's Nose, Lammer Law Burn, 275, 276.
Frodaw Height, 559.
Fruid Water, 142, 143, 144, 200.

G

Gabbro, foliated, 91.
—— of Burnfoot, 90.
—— pegmatite, 473.
Gabsnout, 387, 393, 401, 419.
—— Burn, 393, 394.
Gair Gill, 238.
Gait Crook, 126.

Gala Bank, 253.
Galashiels, 203.
Gala Water, 190, 193, 194, 199, 270.
Galena, 654.
Galloway granite masses, 607.
Gameshope Burn, 139.
Game's Loup, Ballantrae, 441.
Gairland Burn, Spango-Water, 326.
—— —— Haggis rock altered at, 326.
GARDINER, Miss, 35, 77, 617, 633, 637, 645, 646.
Garheugh, 174, 179.
Garlie's Cleuch, Winterhope Burn, 139.
Garliestown Bay, 216.
Garnaburn, Colmonell, 470, 481.
—— Farmhouse, 478.
Garpol Water, Moffat, 131.
Garpool Burn, New Cumnock, 367.
Garryhorn, 378, 379.
—— Burn, 378, 379, 382, 640.
Garthland, 401.
Garvald, 276.
—— Farmhouse, 267, 269.
Garviland, 393, 394.
Gatehouse of Fleet, 213.
Gatelochside Burn, 366, 367.
—— igneous rocks at, 367.
Garwachie, 390.
GEIKIE, Sir A., 15, 16, 18, 209, 431, 437, 465, 523, 586, 590.
—— —— Results of previous investigators summarised in 1867 by, 18.
— Professor JAMES, 15, 16, 507, 560.
General description of Strata—
Sedimentation continuous during Silurian period, 37.
Geological Survey—
—— fossils discovered at Leadhills by R. L. Jack, 18.
—— Mapping of Silurian rocks begun, 15.
—— Order of succession originally adopted by, 19.
— — Palæontological anomalies explained by Barrande's Theory of Colonies, 19.
—— Re-examination of Silurian rocks, 33.
—— Results of re-examination, 35, 36.
Giant's Grave, 236.
Gillespie Burn, 180, 181, 182.
Gipsy Head, 555.
—— Point, 554.
Gimmenbie Burn, Water of Milk, 558.
Girvan Rocks (igneous), 432, 465, 466.
—— —— (unconformable sedimentary series), 484.
—— —— collection of fossils by Mrs. Gray from, 28.
—— —— conflicting palæontological evidence, 26.
—— —— discovery of graptolite zones by C. Lapworth in, 30.
—— —— Lapworth's order of succession in, 29.
—— —— unconformability at base of, 484, 494.
—— —— unconformability in, 31, 541.
Girvan Valley, 462, 501, 507, 522, 523, 527, 544, 546, 547.
—— Water Head, 418.
Gladhouse Water, section, 266.
Glassoch, R. Bladenoch, 391, 419, 420.
Glauconome zone in the Hagshaw Hills, 585.
—— —— in the Pentland Hills, 602.
Glede Knowe, 205.
Glen App, 387, 416, 421, 507.
—— —— fault, 372, 411.
Glenalymer Burn, Sanquhar, 325.
Glenbuck, 582, 583.
Glen Burn, section, 163, 164.
—— —— Euchan Water, 355.
—— —— —— lava at, 354.
Glencaird, 396.
Glencaple Burn, section, 288.
Glencotho, section, 258.
Glendorch, 295, 297.
Glendowran Hill, 824.
Glendrishaig House, Ballantrae, 424.
Glendrissock Hill, 500, 501, 506.
Glendyne Burn, Sanquhar, 301, 302.
Glenessland Burn, 157.
Glen Farmhouse, 164.
Glengaber Burn, Meggat Water, 140.
—— —— Wanlock Water, 291.
—— Hill, 291, 292.
Glengap Burn, 325, 326, 365.
Glengonner Water, 280.
Glenguffock Hill, 325, 326.
Glen Hall, 151.
Glenhapple Moor, 390.
Glenhead, Polifferie Burn, 363.
Glenhowl, 393, 419.
Glenim, 330.
Glenimshaw Burn, 330.
Glenjaan Burn, 346.
Glen Ken, 199.
Glenkiln, section, 146-150.
Glenkip Burn, Snar Water, 294.
Glenlaggie, 408.
Glenlarrie Burn, 355, 356.
—— pillow lavas, 355.
Glenling black shale bands, 174.
—— section, 177, 178, 179.
Glenliscleugh Burn, Crawfordjohn, 322, 323.
Glenlochrie, 505.
Glenlosk Burn, Cog Burn, 297, 298.
Glenluce, 172, 182, 199, 200, 387.
—— diorite, 624.
Glenmaddie Burn, 354.
Glenmanno, 337.
—— Bridge, 337.
Glenmarch Hope Burn, 292.
Glenmartin Burn, Straiton, 547.
Glenmount, Big Hill of, 373.
—— —— lavas and cherts, 373.
—— Wee Hill of, 373.
Glen Muck, Dalmellington, 372.
Glen Plantation, Luce Water, 394, 395.
Glenrae Burn, 320.
Glenruther, 396, 397.
Glenshalloch shales, 533.
Glenskelly Burn, Moniaive, 384.
Glenwells Burn, 531, 532.
—— shales, 531.
Glenwhing Burn, 326.
Glentewing Burn, Duneaton Water, 322.
Glen Trool, sections, 395, 396.
—— —— Lodge, 395.

Glessal Hill, 454.
Glessel Burn, Berbeth, 373.
—— —— lava and cherts in, 373.
Goat Burn, 381.
Gold, 656.
Goodbush Hill, 578.
Gordonston, 347, 350.
Goseland Hill, 242.
Gott, Snar Water, 321.
Grains, Camps Water, 231.
—— Burn, Sanquhar, 308, 309.
Granitites, 91.
Granulitisation of cherts, Benniner Gairy, 362.
—— —— Glen Trool, 395.
—— —— Kells Hills, Loch Doon, 640.
—— —— Spango Water, 326.
Grassfield, 248, 249.
GRAY, Mrs. ROBERT, 27, 28, 490, 494, 495, 503, 509, 510, 511, 517, 518, 521, 524, 525, 526, 529, 530, 532, 536, 538, 540, 543, 546.
Green Burn, Lauderdale, 197.
Green Carli, Menock Water, 329.
Green Hill of Knockgardner, 550.
—— —— Penwhapple, 509.
Greenhill, Selkirk, 208.
Greenknowes Cottage, 410.
Grieston, 208.
—— Quarry, 206.
—— fossils from, 206.
Gregg Water, R. Stinchar, 463.
Grennan, 216.
—— Bay, 186, 187.
—— —— fossils from, 187.
Grey Hill, Girvan, 481.
Greywacke and Slates——
—— —— cleavage of, 211.
—— —— microflaser structure in, 211.
—— —— schistosity, 211.
—— —— sericite in, 211.
Guffock Hill, 308, 309, 310.
Gutterford Burn, Pentland Hills, 591, 593, 603.

H

HABBIE'S HOWE inlier, 604.
Ha' Cleugh, Nithsdale, 330.
Hadyard Hill, 508, 521, 534, 537, 544, 546.
Hæmatite, 655.
—— vein in Dounan Bay, 411.
Haggis rock, 238, 239, 240, 241, 244, 248, 249, 251, 252, 325, 327, 351, 368, 374, 412.
—— —— fossils from, 240.
Hagshaw Hills anticline, 581.
Halketleaths Mill, 215.
Hall Burn, Scar Water, 337.
Halfmark Burn, 378, 382.
HALL, Sir JAMES, 5, 6, 201, 632.
—— —— discovery of fossils in Wrae limestone, 5.
—— —— experiments on folding, 6.
—— —— Fast Castle, folded strata at, 6.
—— —— folds produced by lateral compression, 6.
—— —— granite an igneous rock, 6.
HALL, Sir JAMES, horizontal thrust due to internal heat of the earth, 6.
—— —— intrusions of granite west of Loch Ken, 6.
Hall Burn, Scar Water, 337.
Hamilton Hill, Peebles, 259.
—— —— fossils, 260.
Hangingshaw, 270.
HARDIE, Mr., 593, 595.
Hare Hill, Pentlands, 605.
Hare Hill antimony, 656.
Harehope Burn, 252.
Hareshaw Shepherd's House, 602, 603.
HARKER, ALFRED, 649.
HARKNESS, Professor, 9, 14, 18, 213, 347, 348, 384.
—— —— three anticlines of black shales traced, 9, 10.
—— —— repetition of black shale bands by faults, 10.
—— —— Glenkiln section, 14.
—— —— Barlae flags, 14.
Harry Burn, Lauderdale, 206.
Hartfell section, 133–138.
Hartree Hills, 243.
Hartside, 271.
Harzburgite, 468.
HASWELL, GEORGE C., 16, 17, 599.
HATCH, Dr., 220.
Hawick rocks, 81, 201, 208, 213, 214, 215, 551.
Hawkwood Burn, 217, 223, 224, 246.
Hazel Gill, 239.
Headshaw Burn, Lauderdale, 272.
—— Linn, 138.
Heathery Burn, Sit Burn, 195.
HEDDLE, Professor, 469, 474, 475.
HENDERSON, JOHN, 17, 591, 596, 597, 599, 600, 604.
Henshaw Burn, 598, 599, 600.
Hensol black shale bands, 170.
—— House, 170, 171.
Heriot Water, 267, 269.
Heron, Loch, 392.
Heronsford, Ayrshire, 452.
Heugh, Blythe Water, 207.
High Cairn Hill, 368, 369.
High Knypes, Spango Water, 327.
High Minniwick, 396.
High Newlands, 528, 529.
Hillend, Clovenfords, 204.
—— Water of Deugh, 376.
HINDE, G. J., 34.
—— Radiolaria described by, 34.
History of Previous Research, 5.
Hodge Burn, 114.
Holm Burn, R. Ken, 362.
Holms Water, 231, 258, 263.
—— Waterhead, Glencotho, 262.
Hone-stones, 653.
Hope Burn, Heriot Water, 267, 268.
Hope's Water, Lammermuirs, 276.
HOPKINSON, Mr., 22, 26.
Hornblende-dolerite, 91.
—— -olivine gabbro, 482.
—— -picrite, 470.
—— -schist, 91.
—— —— of Carleton Hill, 456, 457.
—— —— of Laigh Knockclauch, 458.

Horne, John, 19, 33, 640.
Horseman's Burn, 330.
Horse Rock, 540, 542.
Horton Gill, 285, 289.
—— —— *Loganograptus Logani* from, 286.
Houghton, Mr., 468.
Howcan Burn, Cog Burn, 297.
Howe Cleuch, Eyan Water, 143.
Howe Gill, Culter Water, 236, 238.
Howell Bay, 554, 555, 556.
Howe of Laggan, Barr, 463.
Hunter, Dr., 567.
Hunterheck Hill, 210.
Hunt Law, Snar Water, 293.
Hutton, J., 5, 6.
—— Origin of Schistus Mountains, 5.
—— Siccar Point, section, 5.
—— unconformability in Jed Water, 5.
Huxley, Thomas, 14.
Hyndlee, 561.
Hyperite, 612, 613, 617, 624, 625.
—— dyke, 631.

I

Inlier, Bavelaw Castle, 604.
— Carmichael Burn, 586.
— Cheviot Hills, 561.
— Craigenterrie, 605.
— Habbie's Howe, 604.
— Lesmahagow, 570.
— Lyne Water to Green Law, 590.
— Riccarton and Wolfelee, 560.
Innerleithen, 192, 193, 205, 269.
Isle of Whithorn, 551.

J

Jack, R. L., 323.
Jameson, Professor, 6.
—— "Mineralogy of Dumfries," 6.
Jed Water, 561, 562.
Jeffrey Rig, 141.

K

Kello Water, 364.
Kells Farmhouse, Southwick, 610.
Kells Hills, 395.
Kelphope Burn, 273.
— Water, 276.
Ken, Loch, 161, 633.
— R. Valley, 344, 345, 346, 347, 350, 351, 358, 383.
Kennedy's Pass, 446, 459, 494, 498.
Key Gill, Culter Water, 235.
Kidlaw Burn, 276.
Kilbucho Burn, 241, 242.
—— fossils from quarry, 243.
—— grit, 82, 238.
Kilfeather Loup, Luce Water, 400, 401.
Kilgrammie, 505.
Kilintringan Bay, 415.
Killochan, 523, 539.
—— Station, 462, 501, 509.
Kiln Burn, 309–313.
—— —— volcanic rocks of, 311.
Kilnotrie, 169, 170.
Kilranny Burn, 446.
—— Hill, 459, 460.
Kilrubie Hill, 251.
Kingledoors Burn, 199, 232.
Kip Burn, 577, 578.
Kippery, Mulloch Hill, 528.
Kirkandrews Bay, 215.
Kirkbean Burn, 554.
Kirkbride, Sanquhar, 330.
Kirk Burn, Glengonner Water, 283, 285.
Kirkconnel, near Sanquhar, 386.
—— Burn, Shinnel Water, 384.
Kirkcowan, 183.
—— diorite, 624.
Kirkcudbright Bay, 213, 214, 215, 551, 552, 553, 556.
Kirk Hill, Mulloch Hill, 528.
Kirkhoble, River Cree, 396.
Kirkland conglomerate, Girvan, 83, 487.
—— Burn, 488, 501.
—— Hill, River Stinchar, 495.
Kirkland Hills, Sanquhar, 327.
Kirkton of Crawford, 228, 229.
—— railway cutting opposite, 229, 230.
Kirriemore Burn, Minnoch Water, 418.
Kirwan Plantation, 176.
Knarie Burn, 160.
Knipe Hill, New Cumnock, 366.
Knockbain, Ayrshire, 494, 495, 496.
—— Burn, 496.
—— Farmhouse, 512.
—— fossils from Balclatchie mudstones at, 512.
Knock Bay, 415.
Knockbrake, 458.
Knockbrex, 215.
Knockdaw, 457.
—— Hill, 457, 469.
Knockdhu, 451, 453.
—— Bridge, 453.
—— Burn, 451, 499.
Knockdolian, 466, 471.
—— Barns, Stinchar limestone at, 500.
—— Castle, 449, 452.
—— Hill, volcanic rocks of, 449, 452; intrusive igneous rocks of, 470, 471, 478, 481.
Knockdon, Girvan Water, 373.
Knockgardner, Straiton, 544, 547.
Knockgerran shales, 521.
Knockgown, Ballantrae, 427, 428, 429.
—— *Dendrograptus* at, 429.
—— fossils (Glenkiln) from mudstones at, 429.
—— tuffs at, 428.
—— volcanic rocks at, 428.
Knockgray Craig, 385.
Knockingarroch, Water of Deugh, 377.
Knocknairling Burn, 163.
—— Hill, 618, 633, 637.
Knockormal Hill, 466.
Knowe School, Wigtownshire, 397.
Kynance, Cornwall, 476.

L

Ladhope Burn, Galashiels, 203.
Lady Bay, Loch Ryan, 411.
Burn, Craighead, Girvan, 523, 524.
— — Straiton, 547, 549.
Ladyside Burn, Heriot Water, 194, 199.
Ladywell Farmhouse, Trochraigue, 505.
Lagbaes, Cardorkin, 389.
—— Burn, Cardorkin, 388.
Lagbrae Head, Crawick Water, 316.
Laggan, 462.
—— Gill, Glengonner Water, 281, 283.
—— —— Girvan, Balclatchie mudstones at, 512.
—— —— —— fossils from, 512.
Laggish Burn, 417.
Laigh Assel Burn, 522.
Laigh Knockclauch, 456, 458, 472, 479.
—— —— Arenig graptolites at, 458.
Laight Hill, 348.
Lairdmannoch, Upper, 172.
Lamachan, 387, 395.
Lamancha, 248, 250.
Lamb Law, Leithen Water, 266.
Lammer Law, 273, 275.
Lammermuir Hills, Arenig-Llandeilo-Caradoc rocks of, 275–279.
Lane Toll, 460.
Langholm and Dumfries, Wenlock and Ludlow rocks between, 557.
Langholm Lodge, 558, 560.
Langholm and Oxnam, 559.
Langtae Hill, 559.
Lapworth, C., History of Researches, 20–25, 29–33, 36.
—— order of succession of Silurian rocks established in Moffat region, 24.
—— —— —— Girvan area, 29.
—— discovery of Middle Arenig graptolites near Girvan, 31.
—— summary of stratigraphical and palæontological researches, 36.
—— 194, 206, 271, 434, 436, 483, 485, 488, 489, 491, 493, 501, 502, 504, 508, 511, 512, 513, 517, 518, 519, 521, 522, 523, 525, 528, 529, 531, 533, 534, 535, 536, 538, 539, 540, 541, 545, 549, 604.
Larbrax Burn, 413.
Largerie, 344.
Larg Hill, 388.
Larghill Bridge, 164.
Lauder, 196, 201, 206.
Lauder Burn quarries, Tarannon rocks, 206.
Lauderdale, 190, 199.
Lavas, types of Arenig, 84.
Laurie, Mr. Malcolm, 591, 593, 594.
Law Kneis Hill, 212.
Lawrieston, 164, 170.
Lawyer's Cleugh, Burnsands Burn, 336.
Leadburn, 250.
Lead Burn, Wandel Water, 221.
—— —— Elvan Water, Leadhills, 328.
Leaderfoot, R. Tweed, 192.
Leader Water, 196, 207, 271.
Leadhills District, Arenig-Llandeilo-Caradoc rocks of, 281, 303.
Leadhills, galena mines, 654.
Lead mines, Woodhead, Carsphairn, 654.
—— —— Blackcraig, Newton-Stewart, 654.
Leaze Burn, Lesmahagow inlier, 577.
Leffin Knowes, 471.
Leithen Water, 193, 199, 264, 265.
Lesmahagow district, Upper Silurian rocks of, 565.
—— inlier, 570.
—— —— galena from, 654.
Levy, M. Michel, 632, 637.
Liggatcheek, Tarff Water, 172.
Lime Cleugh, Cairn Hill, 331.
Limestone blocks with fossils in Old Red Sandstone conglomerate, 606.
Limestone (Stinchar group)—Aldons, 495; Benan Burn, 487; Bougang, 499; Craighead, 500; Craigneil, 491; Craigwells, 491; Dularg, 490; Dupin, 492; Glenlochrie, 505; Knockdolian Barns, 500; Millenderdale, 496; Minuntion, 489; Tramitchell, 493.
—— (Wrae Group)—Drummelzier, 258; Glencotho, 258; Hamilton Hill, 259; Winkston, 260; Wrae, 255.
Lindean, Selkirk, 192.
—— *Buthograptus laxus* from, 192.
Linholm Burn, 151.
Linn Burn, Druidhill Burn, 333,336.
Linn Dubh, Barrhill, 417.
Little Balmae Farmhouse, 566.
—— Clyde, 211.
—— Dangart, 451, 452.
—— Dod, Heriot Water, 269.
Littlelane, 537.
Little Letterpin, 493.
Littleton Hill, 479, 482.
Livingstone, 213.
Lizard, 466, 469, 471.
—— gabbros, 473.
Llandeilo, general description, 41–47.
—— change of sedimentation N. and S. of R. Stinchar, 45, 46.
—— conditions of deposition of sediment of, 42, 44, 47.
— fossils of, 42, 44, 46.
— Glenkiln shales, 41, 42.
— lateral variation of sediment from S. to N. of tableland, 43, 44.
—— *Loganograptus Logani* in, 44.
—— radiolarian cherts of, 41, 42.
—— unconformability, Girvan, 45, 47.
— volcanic rocks of, 41, 44, 428, 430.
Llandovery, 56.
— conditions of deposition, 59, 62.
— fossils of, 57, 61.
— lateral variation of sediment, 56, 57.
— rocks of, 56, 60.
— sub-divisions in Girvan area, 60.
— zonal graptolites of Central Belt, 58.
—— —— —— in Girvan area, 61.
Lochcraig Head, 139.
— Dee, 387, 395.
— — granite, 610.

Loch Doon, Ayrshire, 362, 416.
—— —— Wigtownshire, 176.
—— —— granite, 326.
Lochhead, Colmonell, 479.
Loch Ken, 156, 214.
—— Lure, 419.
Lochmaben, 213.
Loch Ryan, 410, 411, 416, 507.
—— Skene, 139.
Lochton, Lendal Water, 454, 455, 457, 458, 459, 473.
—— —— Cottage, 458, 472.
—— —— Hill, 455.
—— —— Loch, flaser epidote rocks at, 458.
Loch Trool, 395.
Lochurd Hill, 246.
Lockerbie, 213, 551.
Loganlee Reservoir, 604.
Logan Water, Lesmahagow, 570, 572.
Loganograptus Logani, 286.
Long Phillip Burn, 202.
Long Robin, Kirkcudbright Bay, 552.
Lousiewood Law, 328, 332.
Lorg Burn, section, River Ken, 360.
—— Hill, 358, 359.
Lowther Hills, 262, 332.
—— shales, 82, 232.
Luce Bay, 174, 177, 182, 183, 216.
—— Valley, 387.
—— Water, 387, 401.
—— —— Cross Water, 399.
—— —— —— —— section, 401.
—— —— Main Water, section, 399.
Ludlow rocks, 63-67, 551, 552, 557, 558, 561, 603.
—— —— sub-divisions of, 80-81, 569. 598, 599.
Lugate Head, 196.
—— Water, 190, 195.
LYELL, Sir CHARLES, 7.
Lyne Water, 247, 248, 250, 251, 252, 599, 600, 602.
Lynslie Burn, 603.

M

MACCONOCHIE, A, 33, 283, 347, 567.
MACCOY, Prof., 11, 26, 28.
MACCULLOCH, Dr., 7.
Machars, The, 215.
Machermore, 182.
Macherwhat, 450, 471.
MACLAREN, CHARLES, 7.
—— —— Geology of Fife and the Lothians, 7.
Maclurea zone, 489.
Mains Hill, Ballantrae, 446, 447, 448, 481.
—— —— agglomerate of, 448.
—— —— augite-andesite at, 448.
Main Water of Luce, 399.
Malzie Water, 177, 178.
Manganese, 656.
Manse Rig, Kilbucho, 242.
Manwhill, 343, 346.
March Burn, conglomerate at, 384.
—— —— Kello Water, 365.
March Burn, New Cumnock, section, 368.
—— Cleuch, 330.
—— Port, Portpatrick shore, 412.
March Syke, Rankle Burn, 212.
"Margie Series," 297.
Margree, 347, 349.
—— Burn, section, 349, 350.
Mark Broom Farmhouse, 392.
—— Cleugh, section, 157, 158.
Marnhoul Slate Quarries, 214.
Martour Hill, 342.
MARR, J. E., 59.
MATHIESON, R., 206, 259.
May Farmhouse, sections, near, 176, 177.
M'KIE, Mr., of Knockgerran, 521.
Meigle, 204.
Meikle Arthur Grains, 329.
—— Carco, 313.
—— Letterpin, 462, 512.
—— Ross, 215.
—— Westland, 367.
Melrose, 201, 202.
—— district south of, 207.
Menock Water, Sanquhar, 301, 328, 329, 332.
Mere Cleuch, 233.
Metamorphism, contact, 632–652.
—— of Haggis rock, 326.
—— radiolarian cherts, 326, 362, 395, 640, 641, 642.
Mica-schist pebbles in Pinstane conglomerate, 210.
Mica trap dykes, 628.
Mid Craig, Loch Skene, section, 139.
Middencots, 328.
Middlemoor, 329.
Midlock Water, 231.
Mid Rig, 355.
Miljoan, 485.
Millenderdale, flaser-gabbro at, 477.
—— granulitic gabbro at, 477, 478.
—— Stinchar limestone at, 496.
—— unconformability at, 496.
Milleur Point, 410.
Mill Scar Hill, Crawfordjohn, 322.
Milton Hill, River Stinchar, 485.
Miltonpark Burn, 350.
Mineral wells, 656.
Minnygryle, 349.
Minnoch Water, 395, 396.
—— —— section, 418.
Minuntion, 488, 490.
—— Burn, volcanic tuff in, 460.
—— Quarry, 489, 490.
—— —— fossils from, 490.
Mispickel, 656.
Moak Hill, 455.
Mochrum, 180.
Money Head, 189.
Moniaive, 348, 384.
Monk's Water, 585, 586.
Monograptus Sedgwicki mudstones, 534.
Montraw, 385.
Moorbrock Gairy, 363.
Morrach Farmhouse, Isle of Whithorn, 551.
MOORE, J. CARRICK, 7, 9, 10, 14, 410, 416.
—— —— graptolites discovered by (Loch Ryan), 7.

Moore, J. Carrick, inversion in Silurian rocks of Wigtownshire, 14.
—— —— Fossils discovered in Stinchar limestone, 9.
Moory Sike, 111.
Mossbrae Height, 212.
Mossfenman Brae, 258.
Mosspaul, 551.
Mountbenger, section, 113, 114.
Mountherrick Hill, 327.
Mountskip Wood, 165, 167, 169, 213.
Morroch Bay, 409, 419.
—— section, 401–408.
Mull of Galloway, 183, 188.
—— —— granite mass, 623, 624.
Mulloch Bay, Kirkcudbright shore, 553, 554, 556.
Mulloch Hill, 508, 529, 530.
—— —— conglomerate, 523, 528.
—— —— group, 81, 527, 531.
—— —— quarries, 529, 530.
—— —— sandstones, 528–530.
Murchison, Sir R. I., 10–14, 18.
—— —— anticlinal axis accepted by, 12.
—— —— correlation of Scottish Silurian rocks with those of Wales, 12.
—— —— list of fossils from Ayrshire, 11.
—— —— repetition of black shales due to folding, 12.
—— —— sketch map of coast of Ayrshire, 12.
—— —— subdivision of Silurian rocks of Ayrshire, 12.
—— —— summary of views given in Siluria, 4th edition, 1867, 18.
Muck Water, River Stinchar, 463, 507.
Mutton Hole, 141.
Myoch Bay, 517, 518.

N

Ness, Glen of, 372.
Nether Cairn, New Cumnock, 368.
Nether Cog, 317.
Nether Forrest, Pulharrow Burn, 344, 345.
Nether Glaisters, 159, 160.
Nether Howe Cleuch, flaser greywackes at, 211.
Nether Phawhope, 118.
Nether Whitecleuch Burn, 321, 322, 323.
—— —— section, 321.
Netherlaw Point, 556.
New Channelkirk, 273, 274.
New Cumnock, 366.
—— —— granite, 625.
New Galloway, 161, 200, 213.
Newhall, Cadon Water, 205.
Newlands, 531, 532.
—— series, 527.
—— —— sub-divisions of, 527.
New Luce, 400, 401.
Newton-Stewart, 172, 200, 389, 390.
Nicholson, Professor, 27, 28, 34, 502, 503.
Nicol, Professor James, 7, 9, 11, 13, 18, 206, 262.
—— —— Anticlinal structure of Silurian rocks inferred by, 9.
—— —— graptolites discovered at Grieston by, 7, 206.
—— —— Guide to Geology of Scotland, 8.
—— —— Wrae limestone, fossils from, 8.
Nisbet Burn, Culter Water, 239.
Nith, River, 213, 330-332, 383.
—— —— at Burnmouth, section, 333, 334.
Noblehouse, Arenig lava near, 248.
North Esk, Forfarshire, schistose igneous rocks in, 329.
North Esk, Pentland Hills, 589–600, 603.
North Threave, 528.
Nout Craig, Holms Water, 263.
—— —— Burn, Holms Water, 263.
Nutberry Hill, 570–572, 578.

O

Old Cambus, 209.
—— Harestanes, 246.
—— Milkieston, 263.
—— Water, 163.
—— Whiplaw, 206.
Olivine-enstatite rock, 468.
Ores, 653.
Orthis confinis flags, 487, 489.
Oxnam, 559.

P

Packman's Burn, 202.
Papana Water, section, 276.
Parishholm, 582, 583.
Partland Place, 368.
Parton slate quarries, 214.
Pathhead, 533.
Patie Cleuch, Shinnel Water, 338, 339.
Peach, B. N., 15, 16, 19, 33, 34, 567, 593.
Peat Rig, Bail Hill, 307.
Peathouse Cleuch, Chanlock Water, 337.
Peden's Cleuch, 560.
Penchrise Burn, 559.
Penfrau Burn, 315, 316.
Penkill, 544.
—— Burn, 535, 546.
—— —— River Cree, 172.
—— group, 81, 545.
Pentamerus grits, 531, 532.
—— limestone, 81, 535, 536, 543.
Pentland Hills, 7, 15, 589, 603.
—— —— Davidson on Brachiopoda of, 17.
—— —— fossils discovered by Maclaren, 7.
—— —— fossils described by Salter, 15.
—— —— Haswell on Silurian rocks of, 16, 17.

Pentland Hills, Henderson and Brown on Silurian rocks of, 17, 591.
—— —— —— zone map and sections by, 17.
—— —— survey by A. Geikie, 15, 590.
Penwhapple (Burn) Glen, 508, 515, 519, 533, 534, 535, 537, 538, 539, 542, 546, 547.
Permian breccia, Snar Water, 321.
Petillery Hill, 377.
Petrography of Lower Silurian igneous rocks, 84–91.
Phawhope Burn, 120.
PHILLIPS, JOHN, 7.
Phyllites, 211.
Picotite, 90, 473.
—— veins, 469, 478.
Piedmont Burn, 501.
—— Glen, 522.
Pillow-structure in lavas of Southern Uplands, 84, 85, 86, 280, 367, 390, 431; of Cader Idris, 432; of Ireland, 431; of Saxony and California, 431.
Piltanton Plantation, 409.
Pinbain, 442.
—— Burn, 442, 443, 444, 446, 459, 466, 471, 473, 474.
—— Hill, 445, 446, 459, 460, 472, 473, 498.
—— Shore, section of volcanic rocks, 442, 443.
Pinbreck Hill, R. Stinchar, 463.
Pinmacher, 462, 500.
Pinmerry, 511.
Pinmore, R. Stinchar, 491, 495, 522.
—— Bridge, 495, 496.
—— Mains, 453.
Pinstane conglomerate, quartzite and mica-schist pebbles in, 210.
—— Hill, 210.
Pirn Quarry, Innerleithen, 192, 193.
—— —— —— Llandovery graptolites from, 193.
Pisgah Hill, section, 244.
Pishnack Burn, section, 152, 153, 154.
—— —— plan of, 152.
PLAYER, J. HORT, analyses by, 640, 644.
PLAYFAIR, Professor, 5, 6.
Pleurograptus linearis recorded from Camrie, Glenluce, 393.
Plumbago, 173.
—— at Talnotrie, Newton-Stewart, 173.
Pochriegavin Burn, section, 375.
Podowrin Burn, section of Ludlow rocks in, 582–583.
—— —— —— fossils from, 583.
Polcrag Burn, section and lists of graptolites from, 313.
Polgown, Scar Water, 356.
—— Burn, section, 356–358.
Polhote Burn, section, 371.
Polmoody section, 130.
Polmorlach, 385.
—— Burn, section, 368–371.
Polsalloch Burn, Kello Water, Caradoc volcanic rocks in, 365.
Polshill, New Cumnock, 366–368.
—— granite at, 368.
—— volcanic rocks, 366.
Polshill volcanic rocks altered by granite, 368.
Poltallan Burn, Caradoc volcanic rocks in, 364, 365.
Polthistly Burn, Crawick Water, section, 318, 319.
—— —— —— andesitic tuff in, 319.
Polvaddoch Burn, R. Ken, section, 358.
Polymodie Burn, graptolites from near mouth of, 416.
Pondreigh Burn, Tarannon fossils from, 207.
Ponesk Water, galena from, 655.
Porfido verde antiquo, 84, 425.
Porphyrite Dykes, 615–627.
Portandea, Ballantrae, 387, 421–425, 506, 507.
—— —— section, 421–423.
—— *Dendrograptus* from, 422, 423.
—— volcanic rocks at, 421, 422.
Portayew Bay, 199.
—— —— section, 409.
Port Cardloch, barren flagstones at, 517.
Port Long, Dounan Bay, hæmatite at, 411.
Portmore, Eddleston, section, 253, 254.
—— Loch, 254.
Portobello, Portpatrick Shore, 412.
Portpatrick district, 401–410.
Port Vad, 438, 439.
—— —— pillowy lavas at, 438, 439.
Potburn, section, R., Ettrick, 118.
Poundland, R. Stinchar, 453.
—— Hill, picotite at, 468, 469.
Powskein Burn, 142, 143.
Prickeny Burn, 375.
Priesthaugh Burn, 560.
Priesthill Height, 570.
Priestlaw granite, 625.
Prieston Hill, 453, 454, 470.
PRINGLE, Mr., 208.
Protovirgularia-grits, 545.
Pseudophite, 91, 476.
Pterygotus beds, 574.
Pulharrow Burn, 344, 345.
Pulmaddy Burn, Deugh Water, 344.
Pulnabrick Burn, 395.
Pyked Stane Hill, 246.
Pyroclastic rocks, 87, 88.
Pyroxenite, 465, 473.

Q

Quarrel Hill, 523, 524, 528, 530.
Quartercake Burn, 556.
Quartzite-conglomerate (Downtonian), horizon of, 569; in Lesmahagow inlier, 579; in Hagshaw Hills, 585; in Carmichael Burn inlier, 586; area south of Tinto, 588; in Pentland Hills, 600.
—— pebbles in Pinstane conglomerate, 210.
—— from Highlands, 256.
—— and quartz-schist-pebbles in Craigenputtock conglomerate, 214.
Queensberry grits, 81, 201, 210, 214.—

R

Radiolarian chert in Forfarshire, 329.
Raeberry Castle, 553, 555, 556.
—— Point, 555, 556.
Raeshaw Wood, Ladyside, 270.
Raggen Gill, 225, 227.
Railway cutting south of Abington, 230.
Ramsay, Sir A. C., 13, 15, 209.
Ramsgill Crag, pillowy lava at, 247.
Range Cleuch, sections, 108, 118.
Rankle Burn, Tarannon rocks in, 211, 212.
Rastrites maximus shales, Girvan, 536.
—— —— zone, 81.
Raven Gill, Glencaple, section, 286–288.
— - - - — Arenig fossils at, 286.
— - - - — gabbro in, 286.
— - - - — shelly mudstones at, 288.
—— —— —— volcanic rocks in, 288.
—— —— Dod, 283, 285.
Red Scar Rig, 275.
Ree Burn, Wanlock Water, 290, 291.
Ree Burn, Douglas Water, 582, 583.
Reecleuch Burn, Snar Water, 294.
Reedy Gutter, 291.
Reeve Burn, Spango Water, contact metamorphism at, 326.
Reeve Sike, Camps Water, 231.
Regland, Caradoc graptolites at, 349.
Rein Gill, section and list of Glenkiln-Hartfell graptolites, 223.
Rhinns of Galloway, 183, 215, 216.
Rhombic pyroxene of Ayrshire serpentine, 469.
—— —— analysis of, 469.
Rhymer's Glen, Melrose, section, 190.
—— —— —— fossils from, 191.
Riccarton inlier, 560, 561.
—— Burn, 561.
Richard's Cleuch, 562.
Riddenlees, section, 248, 249.
Rig Burn, fossils from, 657.
Rigs, Tweedsmuir, Birkhill fossils from, 143.
Ringdoon section, 392.
Ringford, 172.
Road metal, 652.
Robb's Craigs, 555.
Romanno Bridge, 250.
—— Mains, 250.
Rome Hill, 217, 225.
Rosenbusch, Professor, 468.
Rough Cleuch, Menock Water, 301, 302.
— Craig, Lorg Hill, 358.
— Gill section, 220.
— Naze, 356.
— Neuk, 530, 531.
—— Shoulder, 358.
Roundstonefoot section, 130.
Rowantree Gutter, 108.
Rule Water, 560.
Ruttonside section, 138.

S

Salachan Farmhouse, 452, 471, 499.
—— Hill, 448, 450, 452, 476.
Salter, J. W., 9–15, 26, 208, 209, 500.
—— —— "Cambridge Catalogue," 26.
—— —— "Monograph of British Trilobites," 26.
—— —— Stinchar limestone and Loch Ryan slates, fossils of, 9.
—— —— Wenlock fossils, Kirkcudbright, 9.
—— —— Wrae limestone, list of fossils from, 8.
Salt Pan Bay, Portpatrick coast, 412, 413.
Sandy Knowe, 270.
Sanquhar, 303, 351, 366.
Sauchet Water, Stenton, section, 279.
Saugh Hill, 527, 533, 534, 537, 539.
—— —— grits, 534, 543, 544.
—— —— group, 81, 527, 531.
Saxonite, 465.
Scab Cleuch, 118, 119.
Scar Burn, 163.
—— Water, 337, 347, 348, 356, 358.
Scart grits, 543.
—— rocks, 542.
Scarty Head, 189.
Schistose-diabase, 228.
Scotston, 247.
—— House, 248.
Sedgwick, Professor Adam, 10, 11, 18, 26, 500.
—— sub-division of Silurian Rocks of Southern Uplands, 10, 11.
Seggholm, Muirkirk, 578, 588.
Selcoth Burn, 105, 107.
—— —— fossil lists from, 106.
Selkirk, 201.
—— Common, 208.
Selkirk, Earl of, 9, 556.
Serpentine, 89, 90, 466.
—— analysis of, 89.
—— Balhamie Hill, 89, 90, 466.
— — Lochton, 472.
—— picotite in, 90.
Shalloch, 540, 541, 543.
—— Hill, Assel Water, 460, 491, 493.
—— Mill, 508, 515, 517, 518, 519.
Shallochbraik, 463.
—— Burn, Ballantrae, 424.
Shank Houp section, 235.
Shank's Castle, Logan Water, 573.
Shelly mudstones, Arenig, 39, 83, 288.
Shiel Burn, Ayrshire, 547, 549.
—— —— Brandleys, 301.
—— —— Crawfordjohn, 303.
—— —— Crawick Water, 317.
Shiel Hill, Crawick Water, 317, 318.
Shielhope section, 140.
Shield Burn, Crawfordjohn, 322, 323.
Shinnel conglomerate, 383.
—— Head, 338, 339.
Shortcleuch Water, Elvan Water, 328.
Shorthope, 119, 120.
—— Burn, 120.
Shortwoodend section, 130.
Siccar Point, 209.
Sim's Burn, 295.
Silver, 656.
Sit Burn, Lugate Water, section, 195.
Skelfhill, 560.
Skeoch section, 163.

Skirling Craigs, 246.
Slate Cleuch, Douglas Burn, section, 141.
Slate quarries, 416, 653.
— Parton, 214.
— Stobo, 262, 653.
Slates and phyllites, 241.
Slimon, Dr., 13, 14, 16.
— discovery of Eurypterids at Lesmahagow, 13.
Slitrig Water, 551, 559.
Slocknamorrow, 412.
Slot Burn, 578.
Slough Burn, 294.
Slunkrainy section, 188, 189.
Smelting mill, Leadhills, 280.
— Wanlockhead, 293.
Smithy Burn, 585.
Snarhead, 293, 324.
—— Hill, 293.
Snar Old Castle, 321.
Water, Leadhills, 293, 294, 324.
— section, 293, 294.
— conglomerate, 320.
— (lower section), 321, 322.
— *Dendrograptus* from, 321.
Soda-felsite-lava at Wrae, 55, 88, 257.
—— —— —— Hamilton Hill, 88, 260.
—— —— —— Glencotho, 88, 258.
South Threave, 524.
Southwick, flaser granite from, 610.
Southwood, 227.
Burn section, 227.
— Rig, 229.
Soutra Hill section, 275.
Sow Burn, Crawick Water, 311.
Sowen Burn, Wanlockhead, section, 293.
—— Dod, Wanlockhead, 293.
Spango Water, 326.
granite, 326, 625.
—— cherts granulitized by, 326.
Spotfore Burn, 313–317.
—— section, 313–317.
—— volcanic rocks of, 314, 315.
Spout Burn, Lorg, R. Ken, 361, 362.
Starfish bed, 525, 526.
—— —— fossils from, 526.
Stennies Water. R. Esk, 557.
Stenton, 279.
Stevenson, Thomas, 8.
— — Geology of Little Ross, Kirkcudbright, 8.
Stevenson Hill, 252.
Still Burn, Fountainhall, 194.
Stinchar, R., 421, 426, 432, 446, 463, 471, 476, 485, 491, 523.
—— limestone group, 485 (see Limestone).
—— —— —— fossils of the, 488, 490, 494, 495, 500, 503, 504.
—— —— —— horizon of the, 47, 83.
— valley, 241, 423, 462, 485, 453, 522.
Straiton, 544, 547, 549.
St. Abbs Head, 208, 209.
St. Medan's Cell, 216.
Stirches Quarry, 208.
Stobo, 200.
—— Slate Quarries, 262, 653.
Stobs Castle, 559.
—— —— Gate, 559.
Stockinray Bay, 445, 459, 460.
—— —— agglomerate at, 445.
—— —— Benan conglomerate at, 445.
—— —— diabase-porphyrite at, 446.
Stonehill, Duneaton Water, 327.
Stoneykirk, 199.
Stony Knowes Hill, 375.
Stoodfold Burn, 309, 311.
—— —— Caradoc volcanic rocks at, 311.
Strifeland Burn, R. Stinchar, 452, 453.
Stroan, Glen Trool, 396.
Stroanfreggan Burn, 343.
Stroanpatrick Burn, 343.
Stroquhairn Burn, 330.
Swallow Port, Portpatrick coast, 412.
Syart Law section, 140.
Syme, I. T., 8.

T

Tableland, Geographical Sub-divisions—
—— —— Belt, Central, 37.
—— —— —— Northern, 37.
—— —— —— Southern, 37.
—— —— —— Girvan area, 37.
—— —— Physical Features of—
—— —— —— area, boundary fault, height, scenery, watersheds, 1–4.
—— —— river systems of, 3.
Tables—showing relative thicknesses of Silurian strata in the South of Scotland, 79.
—— showing sub-divisions of Upper Silurian rocks, 80, 81.
—— —— —— Lower Silurian Rocks, 82, 83.
Tachylite, porphyritic, 445.
Tait, David, 567, 602, 606.
Talla Water, 143, 144, 145.
Talnotrie, plumbago from, 173.
Tannylaggie section, 397, 398, 419, 420.
Tappins group, 83, 372, 423, 424, 426, 430, 462, 463, 464.
—— —— explanation of term, 372 (footnote).
—— Hills, 250, 423, 464.
Tarannon Rocks—
General description—
Rocks, 58, 62.
Fossils, 59, 62.
Conditions of deposition, 59, 62.
Detailed description—
Central Belt, 198–216.
Northern base-line of, 198.
Sub-divisions of, 201, 210, 213.
Girvan, area, 544–547.
Sub-divisions of, 544.
Fossils from, 545, 546, 547.
Tarf Water, Wigtownshire, 183.
Tarff Water, Kirkcudbrightshire, 172.
Tarth Water, 247, 252.
Teall, J. J. H., 211, 259, 261, 308, 312, 319, 431, 437, 445, 457, 468, 469, 473, 476, 477, 478, 481, 482.

Tectonic arrangement of Silurian Strata, 69.
Contact-metamorphism, 77.
Excavation of valley system, 78.
Intrusive igneous rocks, 76.
Isolation of sub-formations by denudation, 69.
Modification of outcrops by pitch of folds, 75.
Period of elevation, 69.
Schistosity and cleavage, 75.
Structural features of Silurian Belts, 71.
Types of curvature, 70, 71.
Tewsgill, Abington, 300.
—— Hill, 217, 225.
Thirlstane Score,—
THOMSON, WYVILLE, 15.
Thornylee, 204, 208.
Thorter Burn, Garvald, 278.
—— Cleuch, Leithen Water, 193.
Threepmuir Reservoir, 606.
Thunderton section, 505.
Tig Water, 452, 494, 499.
Tima Water, 212.
Tinto area (south of), 588.
Tippet Knowe, 239.
Tongue Burn, 352, 353, 354.
Torlane Burn, 350.
Torr Lane, Glen Trool, 396.
Torr Point, 215, 553.
Torr's Cave Bay, 553.
Tottlehams Burn section, 167–169.
Tower Burn, Sanquhar, 305.
Tralodden, 522.
Tramitchell section, 493, 494.
—— limestone Quarries, 493.
TRAQUAIR, Dr. R. H., 565, 578, 588, 593.
—— Note on Silurian Fossil Fishes by, 565–567.
—— Supplementary Note (1899) by, 588.
Trenton limestone, 503.
Trochraigue, 504, 505, 528.
—— Caradoc fossils from, 505.
Trough Burn, Dalmellington, 372.
Trousby, Lugate Water, 196.
Trowdale Glen section, 164–167.
Trow Grain section, 109.
Trowier, inlier of volcanic rocks at, 506.
—— Hill section, 501.
Tynron, 348.
Typical sections, 92–107.
—— —— Dobb's Linn, 92–100.
—— —— Craigmichan Scaurs, 100–107.
Tweed, R., Leaderfoot section, 192.

U

Ulzieside Plantation, 351.
—— —— pillowy lavas at, 351.
Unconformability, local, Cog Burn, 296.
—— —— Glenalymer Burn, 325.
—— —— Kiln Burn, 310.
UNDERWOOD, Rev. Mr., 556.
Upper Appin, Shinnel Water, section, 345, 346.
Upper Bar, Water of Urr, 159.
—— Kidston, Peebles, 260.
Urr Water, 159, 164, 167.
—— section, 159–160.

V

VALLEY, old, filled with Upper Old Red Sandstone strata, 190.
Variolitic diabases of Mont Genèvre, 86.
Volcanic Rocks (Lower Silurian)—
Area occupied by, 74.
Petrography of, 84–91.
Ballantrae area, 421–464.
Bail Hill area, 303–309.
Polshill, New Cumnock, 366–368.
Caradoc—
Wrae, Glencotho, Drummelzier, Hamilton Hill, and Winkston, 257–260.
—— ash or tuff at Camrie Fell, 393.

W

WALKER BURN, section, 205, 206.
Wallace's Cast, Wandel Water, section, 224, 225.
—— —— Caradoc fossils from, 225.
—— —— comparison of fossils with those from Kilbucho conglomerate, 243.
Wandel Water basin, 217–225.
—— —— Mill, 327.
Wanlockhead, 328.
Wanlock Water, sections, 290, 291.
—— —— lower section, 319, 320.
Water of Ae, 152.
Waterhead, Glengonner W., 280.
WAUGH, ANDREW, 208.
Waulk Mill, Tarf Water, 183.
Weatherlaw Linn, Pentland Hills, 597, 598.
Wedderlie Burn, 207.
Wee Queensberry Hill, 152, 154.
Well Hill, Wanlock Water, 292.
Wenlock and Ludlow—
General description—
Rocks, 63, 64, 66.
Fossils, 63, 64, 65, 65, 67.
Conditions of deposition, 64, 67.
Detailed description—
Blair and Straiton area, 547–550.
Southern Belt, 551–563.
Inliers north of the Tableland, Lanarkshire and Ayrshire, 564–576, 581–583, 586; Pentland Hills, 589–599, 600–606.
West Challoch Farm, 395.
Wether Law, 246, 251.
Whaup Hill Station, railway cutting section at, 215.
Wheel Burn, 207.
Whelphill, Midlock Water, 231, 232.

Whelplaw Burn, 207.
Whing Burn, Euchan Water, 352, 353, 354.
Whitecairn Burn, 349.
Whitecleugh, Crawick Water, 321.
White Dyke, 177.
— Spa, Crows Moor, 179.
White Gill, Camps Water, 231.
Whiteholm, Daer Water, 155.
Whitehope Burn, 113.
Whitehouse group, 82, 515, 518.
Whitefield Loch, 182.
White Port, 552, 554, 556.
Whiteside, Nether, 158.
Upper, 159.
— Moor, 158, 159.
Whitestone Cleuch, 329.
Wide Hope Shank Hill, 252.
Wigtown Bay, 551.
Willowford Burn, 562.
Wilson's Burn, Ballantrae, 430.
Wind Gill, 238.
Windy Cleuch Burn, 271, 272.
Dod, 322.
Windy Law, 263.
Windygate Burn, Elvan Water, 328.
Winkston, 260.
— fossils from, 261.
— volcanic rocks at, 261.
Wintercleugh Burn, Abington, 227, 228.
—— —— schistose lava at, 228.
Wolf Cleuch, Dewar Water, 194.
Wolfelee, 560.
Wolfhope Burn, Ewes Water, 557.
Woodfield Burn, 562.
Woodhead Farmhouse, Craighead Hill, 462.
Woodhead Lead Mines, Carsphairn, 378, 654.
Woodland, 527.
Bay, 517, 522, 542, 543.
Point, 542, 543. 544.
Woody Cleuch, 235.
Woolandslee Burn, Leithen Water, section, 193.
Woolshears Hill, Castlecraig, 247.
Wrae, 255–258.
limestone, 232, 256, 257.
— nodules representing the, 232.
— Quarries, 255.
—— plans of, 256.
— fossils from, 257.
— Hill, 255.
— soda-felsite from, 257.
— tuff from, 257.

Y

Young, James, 567.
Young, Professor J., 15, 16.

Z

Zinc ores, 656.

8. DESCRIPTION OF MICRO-PHOTOGRAPHS (PLATES XVIII. TO XXV.).

PLATE XVIII.

1. (6415).—Basic lava; slaggy margin of pillow-shaped mass. 350 yards N. of Port Vad, Ballantrae. Magnified 14 diameters.

The large amygdaloid is mainly filled with calcite. A little interstitial matter may be seen round the margin. The irregular cavity below contains both calcite and interstitial matter. At the upper left-hand margin is seen a portion of a large amygdaloid entirely filled with interstitial matter.

The main mass of the rock is formed of microlitic felspars, augite-granules, chlorite, magnetite, and interstitial matter. The microlitic felspars only can be clearly recognised in the figure.

2. (6415).—Another portion of the same slide. Magnified 27 diameters.

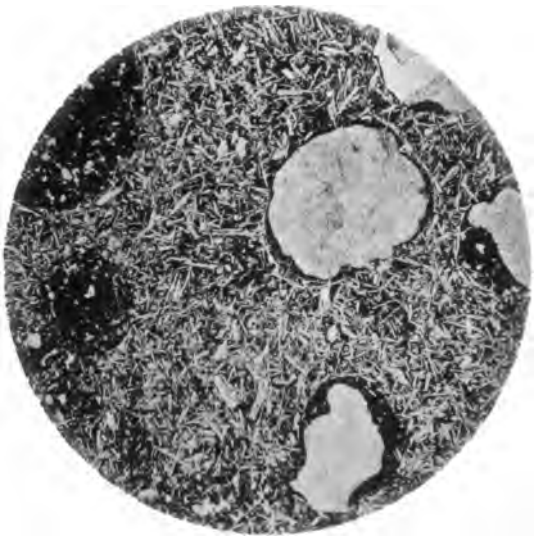


Fig. 1. Basic Lava. × 14.

Fig. 2. Basic Lava. × 27.

PLATE XIX.

1. (6416).—Core of one of the pillow-shaped masses. Magnified 27 diameters.

The portion of the slide represented in the figure contains vesicular lapilli; other portions of the same slide are similar to the main mass of the amygdaloidal rocks.

2. (6419).—Porphyritic lava. On shore 400 yards S. of fifth milestone from Girvan. Magnified 14 diameters.

Large phenocrysts of basic plagioclase in a ground-mass of small felspars, chlorite, small augites, and a little interstitial matter.

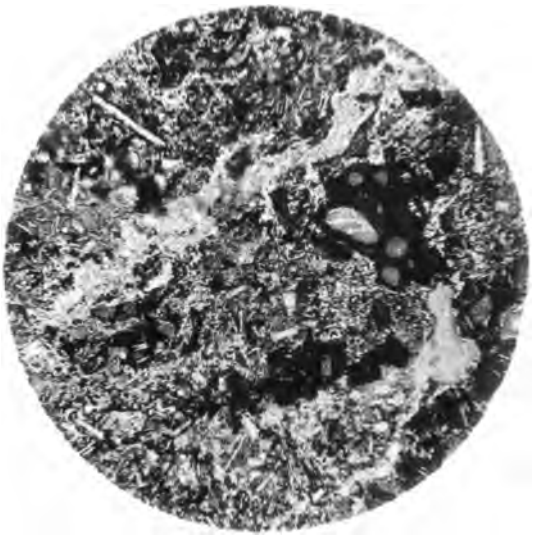


Fig. 1. Lapilli in Basic Lava. × 27.

Fig. 2. Porphyritic Basalt. × 14.

PLATE XX.

1. (5927).—Littleton Hill, Colmonell. Mass surrounded by serpentine. Magnified 14 diameters.

Portion of a large phenocryst of plagioclase containing inclusions of brown hornblende in a ground-mass of brown hornblende, granulitic plagioclase, and iron ore.

2. (6495).—From boss near sheepfold, half a mile due W. of Balhamie Hill. Magnified 27 diameters.

The dark patches are aggregates of brown hornblende; the white patches are aggregates of granulitic felspar. It will be observed that some of the patches of granulitic felspar show decided traces of a lath-shaped form.

It is probable that the original rock was a dolerite.

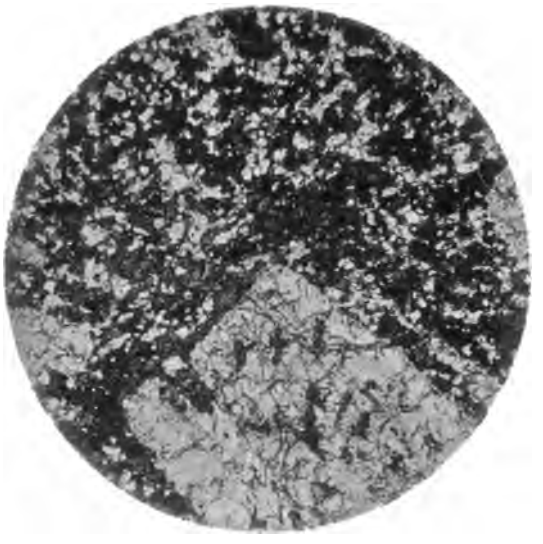


Fig. 1. Plagioclase-hornblende-rock. × 14.

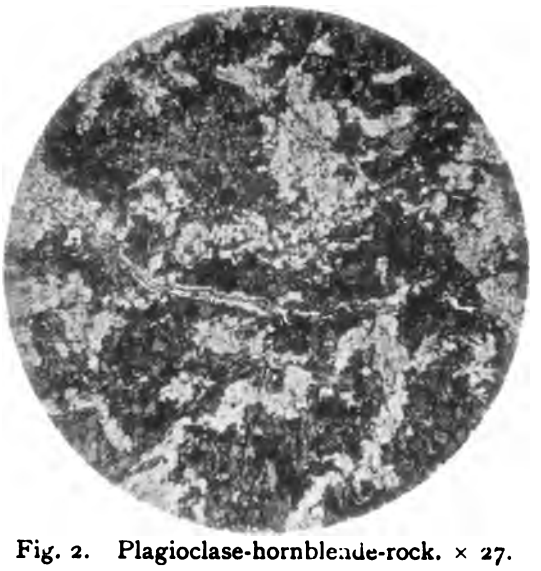


Fig. 2. Plagioclase-hornblende-rock. × 27.

PLATE XXI.

1. (7150).—Crest of Hamilton Hill, Peeblesshire. Soda-felsite. Magnified 27 diameters.

Small phenocrysts of alkali-felspar in a ground-mass mainly composed of microlitic felspars (specimen analysed).

2. (7152).—Winkston Hill. Two miles N. of Peebles. Perlitic felsite. Magnified 27 diameters.

The perlitic cracks are stained with ferric oxide. In the lower part of the figure the dark space represents a portion of a mass of carbonate which appears to replace the felsite, and through which the perlitic cracks pass without interruption.

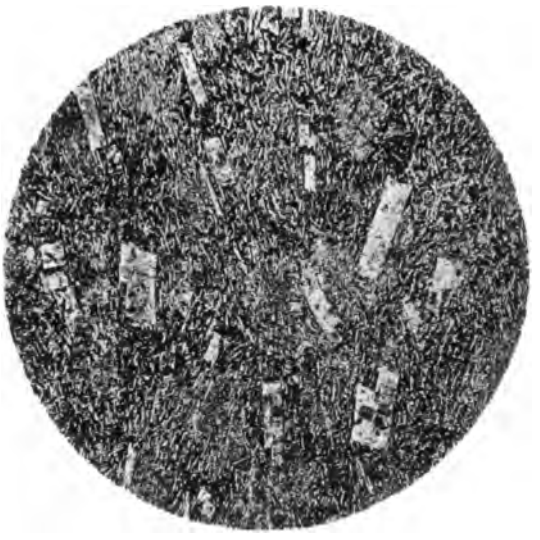


Fig 1. Soda-felsite. × 27.

Fig. 2. Perlitic Felsite. × 27.

PLATE XXII.

1. (6494).—Near old loch, Craig Hill. One mile N.E. of Garnaburn. Magnified 27 diameters.

Banded granulitic rock composed of malacolite, felspar, brown hornblende, and iron ores.

The greater portion of the figure represents a band of malacolite, felspar, and iron ore; at the top and slightly to the left is a small portion of a band formed of hornblende and felspar. This rock is the beerbachite of Chelius.

2. (6453).—Dolerite from centre of dyke, Lendalfoot. Magnified 14 diameters.

The minerals represented are augite, more or less altered plagioclase, and magnetite. The augite shows a marked tendency to elongation in the direction of the vertical axis.

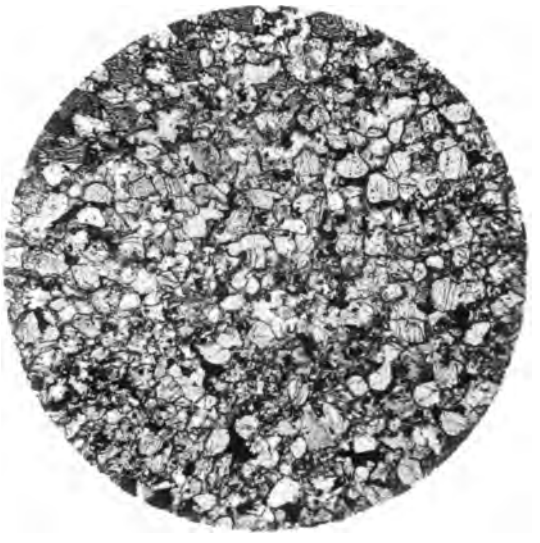


Fig. 1. Granulitic Gabbro. × 27.

Fig. 2. Dolerite. × 14.

PLATE XXIII.

1. (6432).—Hornblende-picrite. Thin dyke-like vein in serpentine, 200 yards west of Balhamie Burn. Magnified 14 diameters.

The dominant mineral is olivine, occurring in large grains, and traversed by the usual anastomosing veins, along which magnetite has been deposited. The spaces between the grains are now occupied by brown hornblende and alteration products after felspar. The amount of felspar originally present must have been very small.

2. (6470).—Coarse-grained ophitic dolerite, east side of Byne Hill, 6 yards from edge of mass. Magnified 14 diameters.

The conspicuous patch near the centre represents an allotriomorphic grain of olivine. The other minerals are augite and more or less turbid plagioclase. A lobe of the olivine grain is seen in contact with augite in the lower or south-east quadrant, and the latter mineral is moulded on the former. As the olivine is clearly allotriomorphic with respect to the felspar, the order of consolidation in this rock has been basic plagioclase, olivine, augite.

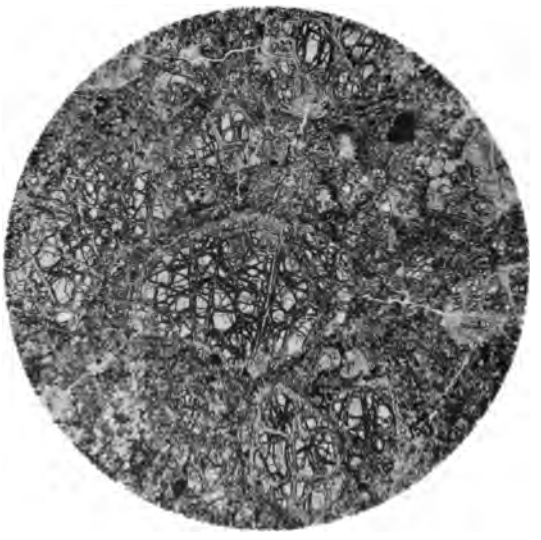


Fig. 1. Hornblende-picrite. × 14.

Fig. 2. Ophitic Dolerite. × 14.

PLATE XXIV.

1. (6470).—Another portion of the same slide. Magnified 14 diameters.

The lower half of the figure is occupied by one large ophitic patch of augite, which is prolonged towards the north-west. The lower part of this patch is clear and unaltered, but the peripheral parts, and especially the north-west prolongation, are formed of an intimate intergrowth of augite and hornblende, and appear dark in the figure. It is probable that the whole patch consolidated as augite, and that the hornblende is therefore secondary. The other portions of the figure represent basic plagioclase.

2. (6571).—Gneissose hornblende biotite-granite. North of Kell's Farm, Southwick. Magnified 14 diameters.

The minerals present in that portion of the slide which is here represented are quartz, felspar, biotite, and hornblende; but the two latter cannot be distinguished in the figure. The interstitial movement which produced the gneissose structure is indicated by the distribution and forms of the opaque streaks and patches (biotite and hornblende).

Fig. 1. Ophitic Dolerite. × 14.

Fig. 2. Gneissose Granitite. × 14.

PLATE XXV.

1. (7050).—Quartz-biotite-hyperite. Black Laggan, Loch Dee. Magnified 14 diameters.

The minerals represented are hypersthene, biotite, felspar, and quartz. A large crystal of hypersthene occurs in the north-west quadrant, and there are several smaller grains of the same mineral in other parts of the figure. The opaque patches represent biotite, and the colourless portions felspar and quartz.

2. (7047).—Camptonite, Black Gairy Hill. Five miles S.W. of Loch Dee. Magnified 14 diameters.

Idiomorphic pale brown hornblende in a felspathic matrix. Under crossed nicols the matrix breaks up into an aggregate of large grains, which mutually interfere with each other. The felspar belongs to the oligoclase-andesine section.

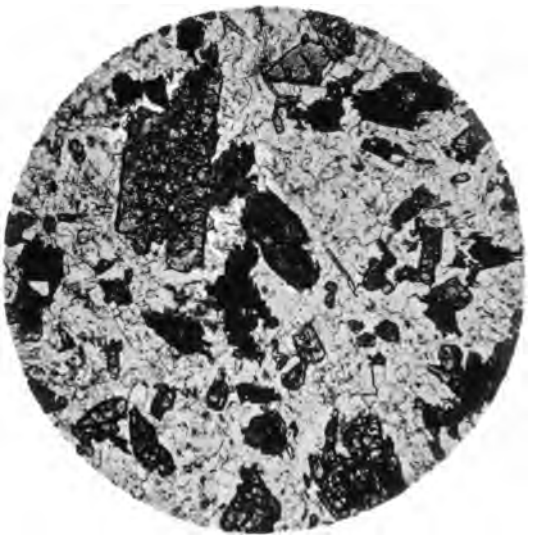


Fig. 1. Quartz-biotite-hyperite. × 14.

Fig. 2. Camptonite. × 14.

EXPLANATION TO PLATE XXVI.

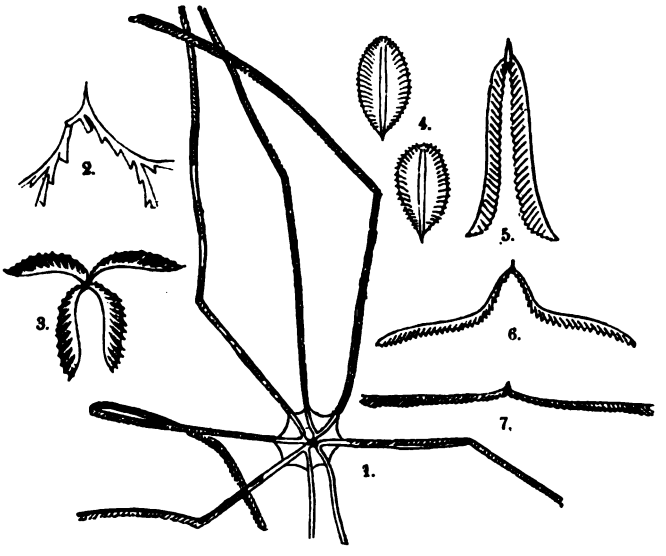
A.—ARENIG AND LOWER LLANDEILO GRAPTOLITES.

1. Dichograptus octobrachiatus (*Hall.*) × ½.
2. Bryograptus Kjerulfi (*Lapw.*) × 2.
3. Tetragraptus bryonoides (*Hall.*)
4. Phyllograptus typus (*Hall.*) × ½.
5. Didymograptus Murchisoni (*Barr.*)
6. ,, v. fractus (*Salt.*)
7. ,, nitidus (*Hall*).

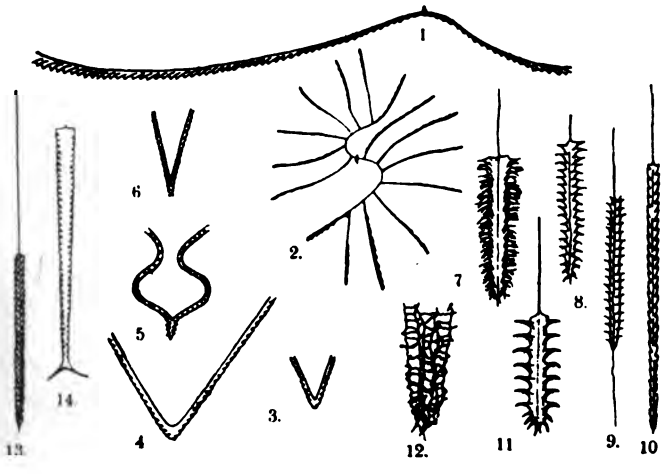
B. UPPER LLANDEILO (GLENKILN) GRAPTOLITES.

1. Didymograptus superstes (*Lapw.*)
2. Cœnograptus gracilis (*Hall.*)
3. Dicellograptus sextans (*Hall.*)
4. ,, divaricatus (*Hall.*)
5. Dicranograptus zic-zac (*Lapw.*)
6. ,, formosus (*Hopk.*)
7. Lasiograptus bimucronatus (*Nich.*)
8. Diplograptus mucronatus (*Hall.*)
9. ,, Whitfieldi (*Hall.*)
10. ,, angustifolius (*Hall.*)
11. Glossograptus Hincksi (*Hopk.*)
12. Clathrograptus cuneiformis (*La...*)
13. Climacograptus Scharenbergi (...)
14. ,, bicornis (*H...*)

PLATE XXVI.



A.



B.

...IG AND LLANDEILO GRAPTOLITES (after Lapworth).

EXPLANATION TO PLATE XXVII.

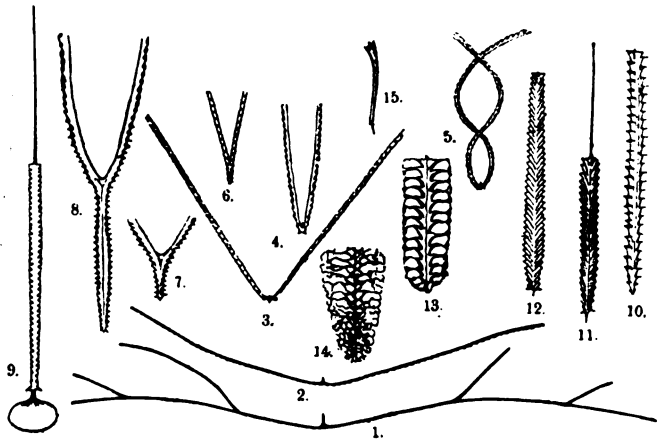
C.—CARADOC (HARTFELL) GRAPTOLITES.

1. Pleurograptus linearis (*Carr.*)
2. Leptograptus flaccidus (*Hall.*)
3. Dicellograptus complanatus (*Lapw.*)
4. ,, Morrisi (*Hopk.*)
5. ,, caduceus (*Lapw.*)
6. Dicranograptus Clingani (*Hopk.*)
7. ,, Nicholsoni (*Hopk.*)
8. ,, ramosus (*Hall.*)
9. Climacograptus Wilsoni (*Lapw.*)
10. Diplograptus quadrimucronatus (*Hall.*)
11. ,, foliaceus (*Murch.*)
12. ,, truncatus (*Lapw.*)
13. Lasiograptus margaritatus (*Lapw.*)
14. Neurograptus fibratus (*Lapw.*)
15. Corynoides calycularis (*Nich.*)

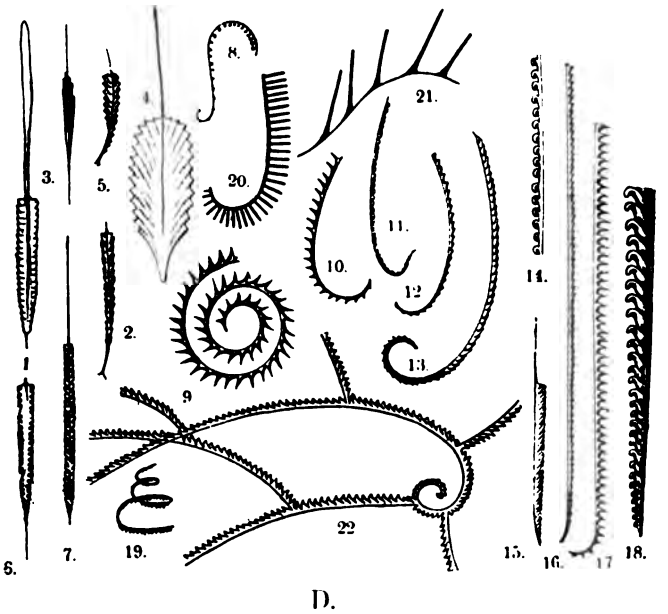
D.—UPPER SILURIAN GRAPTOLITES

1. Diplograptus vesiculosus (*Nich.*)
2. ,, acuminatus (*Nich.*)
3. Cephalograptus cometa (*Geinitz.*)
4. Petalograptus folium (*His.*)
5. Dimorphograptus Swanstoni (*Lapw.*)
6. Climacograptus rectangularis (*M'Coy.*)
7. ,, normalis (*Lapw.*)
8. Monograptus crispus (*Lapw.*)
9. .. spiralis (*Geinitz.*)
10. . triangulatus (*Harkn.*)
11. .. exiguus (*Nich.*)
12. .. gregarius (*Lapw.*)
13. .. cyphus (*Lapw.*)
14. . lobiferus (*M'Coy.*)
15. .. colonus (*Barr.*)
16. .. jaculum (*Lapw.*)
17. . Sedgwicki (*Portl.*)
18. . priodon (*Bronn.*)
19. .. turriculatus (*Barr.*)
20. Rastrites perigrinus (*Barr.*)
21. ,, maximus (*Carr.*)
22. Cyrtograptus Murchisoni (*Carr.*)

PLATE XXVII.

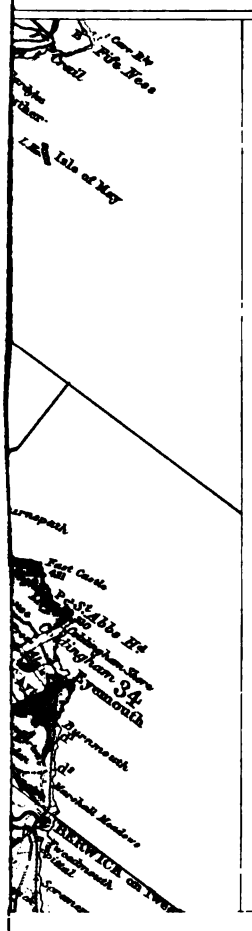


C.



D.

CARADOC AND UPPER SILURIAN GRAPTOLITES (after Lapworth).



INDEX MAP
OF THE
SILURIAN ROCKS
OF THE
SOUTH OF SCOTLAND

Scale 1:633,600 - 10 Miles to an Inch
0 5 10 15 20

TABLE OF SIGNS AND COLOURS.

SILURIAN
- Upper
  - *Downtonian.*
  - *Ludlow-Wenlock.*
  - b^e *Llandovery. & Tarannon*
- Lower
  - *Limestone* — b^z *Caradoc-Llandeilo.*
  - *Radiolarian Chert* — *Arenig (in part).*

DUS ROCKS
- *Contemporaneous*
  - $Tb^{a,z}$ *Tuff, Agglomerate, &c.*
  - *Diabase and Andesite-lavas, &c.*
- *Serpentine, Gabbro, &c.*

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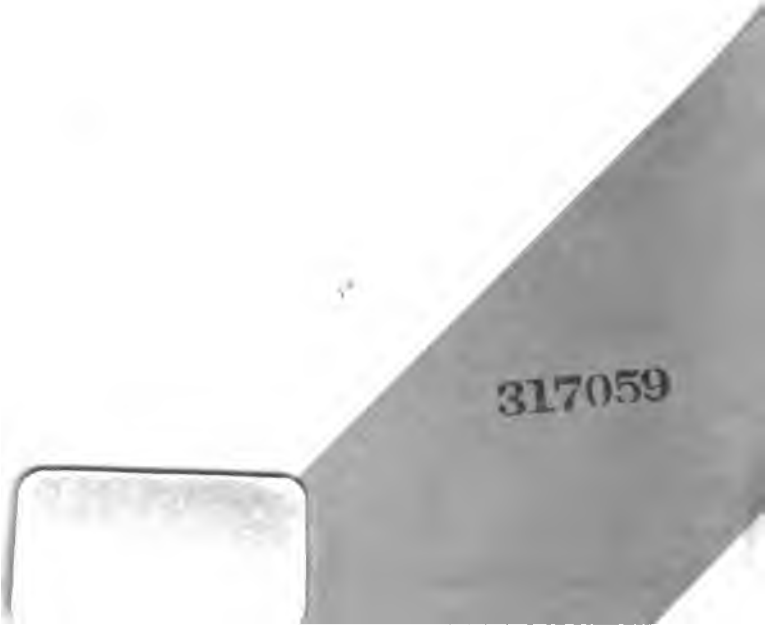
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